HOW TO OBSERVE.

GEOLOGY.

BY

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ADVERTISEMENT.

"Half a word fixed upon, or near the spot, is worth a cart-load of recollection."—Gray.

Sir John Herschel, in his Discourse on the study of Natural Philosophy, remarks that "to make a perfect observer in any science, an extensive acquaintance is requisite not only with the particular science to which the observations relate, but also with every branch of knowledge which may enable him to appreciate the effects of extraneous and disturbing causes. Yet," he continues, "there is scarcely any well-informed person who, if he has but the will, has not also the power to add something essential to the general stock of knowledge, if he will only observe regularly and methodically some particular class of facts, which may most excite his attention, or which his situation may best enable him to study with effect. To instance one or two subjects which *can* only be effectually improved by the united observations of great numbers widely dispersed:—Meteorology, one of the most complicated but important branches of science,

is at the same time one in which any person who will attend to plain rules, and bestow the necessary degree of attention, may do effectual service. What benefits has not geology reaped from the activity of industrious individuals, who, setting aside all theoretical views, have been content to exercise the useful and highly entertaining task of collecting specimens from the countries which they visit? In short, there is no branch of science whatever, in which at least, if useful and sensible queries were distinctly proposed, an immense mass of valuable information might not be collected from those who, in their various lines of life at home or abroad, stationary or in travel, would gladly avail themselves of opportunities of being useful."

These remarks, which gave rise to the idea of a work to be entitled "How to Observe," afford a sufficient indication of its object.

As yet, little has been done towards furnishing detailed instructions to observers. The chief exception to this remark which occurs to us is supplied in the directions contained in Mr. Babbage's excellent work on the Economy of Manufactures. The advantages and pleasures to be derived from accurate observation have indeed been often pointed out; and nowhere have they been better enforced than in the admirable tale of "*Eyes and no Eyes*" in "*Evenings at Home.*" Perhaps, however, the best mode of exciting the love of observation is, by teaching "How to Observe." With this end it was originally intended to produce, in one or two volumes, a series of hints for travellers and students, calling their attention to the points necessary for inquiry or observation in the different branches

of Geology, Natural History, Agriculture, the Fine Arts, General Statistics, and Social Manners. On consideration, however, it was determined somewhat to extend the plan, and to separate the great divisions of the field of observation, so that those whose tastes led them to one particular branch of inquiry might not be encumbered with other parts in which they do not feel an equal interest. Thus, the present Volume on Geology is complete in itself, although contained in the general plan of the series.

It is hoped, that whilst "How to Observe" will afford assistance to the scientific traveller and student, it will also be the means of inducing others to collect information on all or some of the heads noticed. Thus the listless idler may be changed into an inquiring and useful observer, and may acquire the power of converting a dull and dreary road into a district teeming with interest and pleasure. To acquire this power, it is not necessary that the observer should be profoundly skilled in all the subjects that come under his observation. He may soon acquire sufficient knowledge to appreciate what he sees, and to express what he feels. The charm that such habits of observation bestow upon the descriptions of the commonest things is evident in those works in which the observer expresses what he has seen with his own eyes simply and correctly. What reader is there who has not risen with delight from every fresh perusal of White's Natural History of Selborne, a work at once showing the importance of accurate and detailed observation, and the small quantity of scientific knowledge requisite to produce that which is both valuable and interesting. On the other

hand, the writings of St. Pierre, abounding with eloquence and picturesque descriptions, are now nearly forgotten, because they are wanting in that accuracy and minute observation which alone can command a lasting interest.

H. B. K.

London, June 1st, 1835.

CONTENTS.

PART I.

PART II.

PART III.

HOW TO OBSERVE.

GEOLOGY.

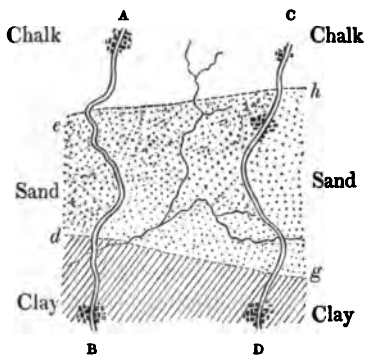
PART I.

Geological observations may be conveniently classed under two heads: first, those which bear immediately on Geology viewed strictly as a science; and secondly, those which show its connexion with the various necessities and comforts of mankind, such as agriculture, mining, building, &c. We shall, in the first place, endeavour to point out the manner in which those who desire to advance the science of Geology may effectively do so, though they may as yet be little acquainted with it, and then proceed to consider the second class of observations, which have, in general, been too much neglected.

There are probably few so little observant of natural objects as not to have remarked that the appearances of countries differed materially according to their soils, and that these again were connected with the kinds of mineral substances found beneath them, such as sands, clays, and various kinds of solid rock. It must also have been observed, while travelling in particular directions over lines of country not far removed from each other, that a succession of similar kinds of soil

or rock frequently occurred; so that if the points where the various changes took place in the different roads were marked upon a map, and that lines were drawn from point to point where the same changes of soil or rock were observed, certain portions of country would be marked off in which the same kind of soil or rock would prevail.

Fig. 1.



Let us suppose that a traveller takes his course from B to A by the road B A, and that the town or village B stands upon clay which he finds is continued to *d*, where sand forms the soil and rock of the country. The traveller would probably class the country he has passed over among the clay districts. Let us further suppose that the same observer, in the prosecution of his journey, finds the sandy country to end at *e*, after which chalk forms the rock to the termination of his journey at A. The traveller would scarcely fail to consider the district he has traversed as composed, in succession, of clay, sands, and chalk; but he would still

be unacquainted with the direction taken by any of these kinds of country.

Let us now consider that the same traveller had occasion to pass over another road, D C, to a certain extent parallel to the former, B A, but distant from it a few miles, and that he found a clay at D, similar to that on which B is situated. Our observer would now most probably conclude that the clayey country of B extended to D. If in the progress of his journey the traveller quits the clay at *g*, and finds the same kind of sandy rock and soil that he had previously observed at *d* on the road B A, and further if at *h* he enters upon the same kind of chalky country that he found at *e* on the other road, he might be induced to draw lines on his map from *d* to *g*, and from *e* to *h*, which would thus divide the portion of country included between the roads B A and D C into three parts—one clayey, another sandy, and the third chalky.

Having advanced thus far in what may be considered a rude attempt at a geological map, the observer may probably infer that there is something like a succession of mineral substances in this part of the country, and be induced to travel over other portions of the district, to the right and left of those he has thus noticed, to see if the same kind of succession continued in those directions; and finding this, he might conclude that soils, or rather the rocks or mineral substances whence they are principally derived, are not confusedly mixed up with each other, but that they occur in a certain order of succession, viewing the subject more generally. Having arrived at this conclusion, his next step would probably be to ascertain whether these mineral sub-

stances or rocks rested upon each other; and if so, their relative order of superposition. We will suppose, for the sake of illustration, that he finds the clay, as seen in the annexed section,* Fig. 2, to rest upon the

Fig. 2.

sands, and these again on the chalk. Having clearly ascertained this fact in several places, he could not be otherwise than convinced that, in the district examined, these mineral substances or rocks succeeded each other in the order represented in the section, which may at the same time afford a rough idea of the geological structure of the country near London, the clay being termed the 'London clay,' because the metropolis (L) stands upon it, beneath which are certain sands interstratified with clays (named plastic because used in pottery) that in their turn repose upon chalk, which rises in hills at various distances to the S., W., and N. of the metropolis.

* A geological section is considered to be vertical, unless otherwise stated. Like other sections, it is supposed to be some material thing divided; so that one part being removed, the structure of the other part is well seen. Thus, when we divide an orange or an apple, we make a section which exposes their interior structure, which is otherwise concealed. Some geological sections are natural, such as those afforded by sea-cliffs; some are artificial, such as deep cuts for roads and other purposes; while others are ideal, like that in the text, being constructed from the knowledge of various facts which render them either highly probable or almost certain,—it, of course, being understood that all possible care has been used in their construction.

Having, from these simple observations, ascertained that some rocks at least succeed each other in a certain order, an intelligent person would probably have his curiosity so far stimulated as to inquire whether other observers have remarked similar successions of rocks in other districts and countries. Finding that the subject had long engaged the attention of several other persons, he would naturally be anxious to learn the conclusions they had deduced from their observations, as also 'how to observe' any facts he may chance to meet with, in order that he should obtain not only a general idea of existing knowledge on the subject, but also the power of employing his time to the best advantage by not sacrificing it in observing things of little or no importance. It is our object to afford this general idea of the present state of geology, with directions to the traveller and student 'how to observe,' so that their labour may not be thrown away; trusting also that some few who may peruse these pages, and who have not hitherto attended to the subject, may be induced to observe and record facts that may advance the science, and which might otherwise be passed unnoticed.

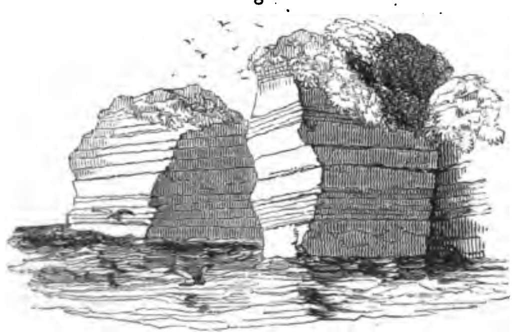
The researches of Geologists have taught them that the rocks* which constitute the visible solid surface of our earth have either been deposited from water where, for the time, the substances of which they are composed

* The term 'rock' is applied by Geologists to all kinds of coherent mineral masses composing the solid crust of our globe, whether they be hard or not. Thus various clays, marls, soft sandstones, and the like, are termed rocks, when they form portions of the series of mineral masses composing land. Even incoherent sands are termed rocks when they constitute a component part of a series of beds or strata.

were chemically or mechanically suspended, or have once been in a liquid melted state from the action of heat upon them. The former are termed aqueous, and the latter igneous rocks, from the nature of their origin. Rocks are also classed under the heads of 'stratified' and 'unstratified;' terms considered synonymous with 'aqueous' and 'igneous.' There are objections to these terms, as will be perceived in the sequel; but as they do not outbalance their convenience in the present state of geology, we shall employ those of 'stratified' and 'unstratified,' as is now mostly commonly done.

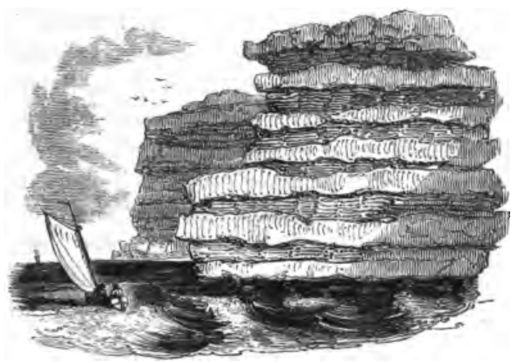
When rocks are divided into beds like the leaves of a book, or several books or pieces of cloth piled upon each other, they are said to be stratified. When an

Fig. 3.



observer finds a series of beds resting upon each other as represented in the cliffs, Fig. 3, he has before him a rock or rocks said to be stratified. It is, however, by no means necessary that the rocks should be divided into beds as flat as the leaves of a book, or as pieces of cloth laid upon each other, to entitle them to the term

stratified. Such beds as those represented in the annexed sketch (Fig. 4) would still be termed strati-



fied. When no traces of beds can be detected, and the rock merely forms a great mass of mineral matter, without other lines than those of cleavage or joints, to be noticed hereafter, it is said to be unstratified. Such rocks have frequently the heavy lumpy character represented beneath (Fig. 5).

The stratified rocks are divided into two classes, the 'fossiliferous' and the 'non-fossiliferous;' the former containing the remains of animals and plants which have once existed, and whose exuviæ, found in various states of preservation and mineralization, are commonly termed fossils or organic remains, while the latter afford no traces of such exuviæ. These terms are applied to the rocks in question as masses; for though the non-fossiliferous rocks are never found to contain organic remains, many beds among the fossiliferous are also without such exuviæ, and might therefore, as far as regarded themselves, be termed non-fossiliferous; but being associated as the bed *c* (Fig. 6) is with *a*, *b*, *d*,

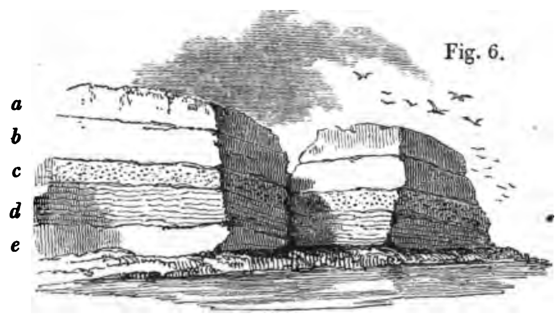


Fig. 6.

and *e*, organic remains being detected in the latter, while they are not found in the bed *c*, they are necessarily included among the fossiliferous class, the absence of fossils being accidental and due to particular circumstances.

The non-fossiliferous rocks are also known by the name of 'primary,' because they are the lowest stratified rocks with which we are acquainted, and hence are considered to have been first formed. Among them

we observe facts which render it necessary that we should, in the true spirit of philosophical inquiry, be extremely cautious in supposing that all beds of mineral matter, or stratified rocks, have been deposited from water. It is not our intention to enter into a discussion on this head, referring to the various treatises on geology for information on the subject; but we mention it to guard the reader from a too ready acquiescence in the belief that all rocks divided into beds, or stratified, particularly among the non-fossiliferous class, are necessarily of aqueous origin.

The non-fossiliferous rocks are for the most part formed of a mixture of a few minerals, the most important of which are quartz, felspar (common and compact), hornblende, mica, schorl, garnet, chlorite, talc, and steatite. A great variety of others occasionally enter into their composition; and one, carbonate of lime, sometimes constitutes whole associated rocks, most frequently in the form of statuary marble. It rarely happens that these rocks are not crystalline or subcrystalline. For the most part they form confused mixtures of two, three, or more of these minerals; and are then known, according to the particular mixture, by different names,—such as *gneiss*, *mica slate*, *talcose slate*, *hornblende rocks*, &c. For particular descriptions of these rocks we must refer to treatises on geology; recommending the reader, if unacquainted with the subject, to dedicate a short time in some good cabinet or museum to the study of the rocks in question, in company with a competent person, by which he will learn more in a few hours than in weeks spent in the mere perusal of descriptions. It may however be remarked, that, viewed chemically, the non-fossiliferous rocks constitute

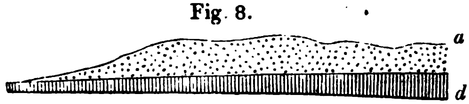
a mass of silicates, among which carbonates are very sparingly disseminated. The principal silicates are those of alumina, potash, soda, magnesia, and lime; and the carbonates, those of lime and magnesia. Silica is the chief ingredient, alumina the next important substance; and then follow potash, magnesia, and soda. Lime and fluoric acid are extensively disseminated in small quantities, and the oxides of iron and manganese are also common, the former greatly predominating.

Upon these repose the fossiliferous rocks; and in them we have evidence that animal and vegetable life existed on our planet before such rocks were formed, since their remains are detected in them. Among the members of the non-fossiliferous class it cannot be said that any particular order of superposition is observable; though, viewed in the mass, the particular mineral compounds named gneiss and mica slate may be said to prevail in its lowest parts. With the fossiliferous rocks, however, the case is different: among them we find a certain order of superposition which has never been found inverted; that is to say, if the order be that

Fig. 7.

of *a*, *b*, *c*, *d*, in the annexed section (Fig. 7), we never find *d* resting upon *a*, or *c* upon *b*, though we may find

Fig. 8.



a resting upon *d*, as above (Fig. 8), either from *b* and *c* never having been formed in that particular situation, or, having been so, they were swept away before the production of *a*, which would necessarily cause *a* to rest immediately upon *d*.

When we state that a given order of superposition reigns among the fossiliferous rocks, it must not be understood that particular mineral compounds are not repeated in the series; for in fact they are so repeated, various sandstones, clays, and limestones often differing slightly, if at all, from each other, following no more order as mineral substances than the non-fossiliferous rocks noticed above. By a given order of superposition among the fossiliferous rocks, we mean that certain masses of mineral substances, no matter what kind of mineral substances they may be, have been produced at distinct geological periods, one after the other; and that, as far as researches have yet extended in Europe, where they have been most studied, they contain, as masses, certain assemblages of organic remains not detected in the others. That is, if, for the sake of illustration, we suppose a series of fossiliferous

Fig. 9.

a b c d e f g h i k l m n o

rocks, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, *i*, *k*, *l*, *m*, *n*, *o*, to rest upon one another as in the above diagram, (though it must not be supposed that such a number of fossiliferous rocks ever succeed each other in nature with such perfect regularity and parallelism,) each would contain

organic remains differing as a whole from those discovered in the others, either above or beneath it; though *a*, *e*, *g*, *m*, may be sandstones; *b*, *d*, *h*, *k*, *o*, shales or clays; and *c*, *f*, *i*, *l*, *n*, limestones.

The fossiliferous rocks have, for convenience, been arranged in groups bearing various names, which in general show the countries where each group has been more particularly studied or developed. As these rocks are chiefly of mechanical origin, though many are evidently precipitates from chemical solutions, it cannot be expected that any great uniformity of mineral structure should be observed over very extended areas, far less that we should find the same mineral composition in rocks of equal age over the face of the globe: —unless, indeed, we suppose equal circumstances to obtain over the whole superficies of our planet at the same times; a supposition evidently absurd, when rocks of mechanical origin are concerned,—that is, those which are deposits from water in which their component parts have been either mechanically suspended or propelled onwards. In order, however, to enable the reader to become acquainted with those mineralogical compositions which have been considered characteristic of the fossiliferous rocks within certain comparatively minor areas, we have in the following table, exhibiting the order of superposition and the subdivisions of the fossiliferous groups, given a short notice of the mineral structure of the rocks beneath the supracretaceous or tertiary beds; premising that such structures are merely characteristic of more or less limited areas, as we shall have occasion still further to insist upon.

List of the Fossiliferous Rocks of part of Western Europe, in the descending Order.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
1. Modern.		Detritus of various kinds deposited from water in which it was mechanically suspended, or by which it was forced forward; modern calcareous, siliceous, and other chemical deposits from water; coral islands, reefs, &c.
2. Supracretaceous. (*Tertiary* rocks of the improved Wernerian classification; *superior* rocks of Conybeare.)	Divided by Lyell, who retains the name *tertiary* for this group, into four subgroups; *viz.* newer pliocene, older pliocene, miocene, and eocene.	Detritus of various kinds deposited from water; calcareous, siliceous, and other deposits from chemical solutions, &c.
3. Cretaceous. (Highest of the *secondary* rocks of the improved Wernerian classification; highest of the *supermedial* rocks of Conybeare.)	*a.* Chalk.	The well-known calcareous substance so named, mixed with flints, particularly in its upper part.
	b. Upper green sand.	An arenaceous rock, for the most part very calcareous, in which green grains of silicate of iron are abundant.
	c. Gault.	An argillaceous deposit of a bluish grey colour, containing much calcareous matter.
	d. Lower green sand.	Sands and sandstones, principally of ferruginous or green colours, the latter prevailing in the lower portions.
4. Oolitic.	*a.* Portland stone.	Beds of an oolitic limestone, or roestone, associated with compact limestone beds, flint and chert.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
Oolitic *(continued.)*	*b.* Portland, or Kimmeridge sands.	Calcareo-siliceous sands and concretions.
	c. Kimmeridge clay.	An argillo-calcareous deposit, sometimes carbonaceous.
	d. Upper calcareous grit.	An arenaceous deposit.
	e. Coral rag.	So named from an abundance of fossil corals generally detected in it. The oolitic limestones associated with it are sometimes of so large a grain as to be termed *pisolite*.
	f. Lower calcareous grit.	An arenaceous rock.
	g. Oxford clay.	A grey argillo-calcareous deposit, in the lower part of which a calcareous sandstone, named Kelloway rock, it often developed.
	h. Compound great oolite: including, in the descending order, 1. Cornbrash, 2. Forest marble, 3. Bradford clay, 4. Great or Bath oolite.	A series of calcareous rocks, compact, oolitic, and friable; sometimes associated with clays or marls. A rock, remarkable for its organic contents, and named Stonesfield slate, sometimes forms the base of the great oolite.
	i. Fuller's earth.	An argillaceous deposit, so named because fuller's earth is obtained from it in some localities.
	k. Inferior oolite.	The upper part formed of calcareous beds in which grains and small nodules of hydrate of iron are abundant, while the lower part principally consists of calcareo-siliceous sands and concretions.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
Oolitic *(continued.)*	*l.* Lias.	An argillo-calcareous deposit, in which beds of argillaceous limestones are frequently developed, particularly in the lower portions.
5. Red sandstone.	*a.* Variegated or red marl.	Marls of various tints of red, blue, grey, green, and white; the former greatly predominating. Gypsum is frequently found in them, and rock salt is occasionally detected.
	b, Muschelkalk.	Limestone beds of variable texture, but most frequently grey and compact. This rock is occasionally dolomitic.
	c. Red or variegated sandstone.	An arenaceous deposit, principally argillaceous and siliceous, of various tints of green, white, blue, and red; the latter greatly predominating. Occasionally contains masses of gypsum and rock salt.
	d. Zechstein, or magnesian limestone.	Limestone beds, in which carbonate of magnesia is disseminated in variable quantities, so that the rock sometimes becomes the crystalline compound of the carbonates of magnesia and lime named *dolomite.* The whole rests upon a marl slate, named *kupferschiefer,* because it contains copper in Germany.
	e. Rothliegendes.	A series of red sandstones and conglomerates, occasionally intermingled with red marls or clays. In some situations the sandstones prevail; in the others, the conglomerates; the latter generally occupying the lower parts.

GROUP.	SUBDIVISIONS.	MINERAL STRUCTURE.
6. Carboniferous. (The authors who employ the improved Wernerian classification vary in this part of the series. Some commence the *transition* rocks with *a*, others with *b*, and others again with *c*.) *Medial* rocks of Conybeare.	*a*. Coal measures.	A variety of shales, sandstones, and occasionally conglomerates; among which coal-beds, differing considerably in thickness, are associated.
	b. Carboniferous limestone.	Compact limestones, for the most part of a grey tint, often sufficiently hard to be employed as marble.
	c. Old red sandstone	A variety of sandstones, chiefly red, among which conglomerates sometimes occur, as also calcareous portions, named *cornstones*.
7. Grauwacke . . (*Transition* rocks of the Wernerian classification; — *sub-medial* rocks of Conybeare.) (Higher portion, the *Silurian system* of Murchison;—central and lower portions, the *Cambrian system* of Sedgwick.)	. .	A considerable accumulation of arenaceous rocks, among which conglomerates occasionally occur. It is chiefly composed of argillaceous and siliceous matter, forming slates and sandstones. Limestones in exceedingly subordinate quantities occur in various parts of the series, and beds of anthracite are sometimes detected in it. Its tints are principally grey and brown, but red is here and there found in all parts of this series. The lower portions appear to graduate, principally by an increase of associated crystalline strata, into the non-fossiliferous rocks.

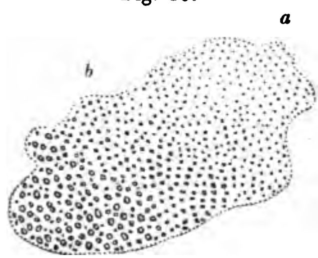
We have said that the mineral structures of the groups and their subdivisions, above noticed, could only be considered characteristic of minor areas; and we may cite in illustration, that while the compound great oolite of Somerset and Wilts is formed principally of calcareous matter enveloping a great abundance

of marine organic remains, its equivalent in Yorkshire is chiefly composed of arenaceous and shale beds with associated coal, the remains of terrestrial plants being exceedingly abundant, while marine exuviæ and the calcareous strata containing them are of a very subordinate character. Again, the old red sandstone, which in Herefordshire is an important arenaceous rock, is in the North of England represented by a conglomerate, sometimes of inconsiderable thickness. The carboniferous limestone also of Southern England, in which coal does not occur and limestone so greatly prevails, is in Northern England represented by sandstones, shales, and coal-beds, the limestone becoming to a certain degree subordinate. On the other hand, the mineralogical character of some groups, or their subdivisions, is constant, or nearly so, over considerable areas. We may cite as illustrative of this fact the well-known white chalk, which preserves its mineral character from the borders of the Sea of Azof, through part of Russia, Poland, Sweden, the northern parts of Germany, the British Islands, and in a large portion of France. Certain argillaceous portions of the oolitic group cover extensive areas, and the general mineral character of the grauwacke is remarkably similar in Europe and North America.

The reader may here demand the utility of observing the mineralogical characters of these rocks at all, since they are thus changeable. A little reflection will, however, show him that to observe these changes is particularly important, since they prove that equal circumstances have not obtained throughout the area occupied by any given group of rocks, or its subdivisions, during

the period of its or their formation, and that by noting the kind of changes which take place he may approximate towards a knowledge of the circumstances which have produced them.

Fig. 10.



Let *a*, *b*, *c*, (Fig. 10) represent an area occupied by a mechanical rock, that is, one formed of the detritus of pre-existing rocks,—an area which for the sake of illustration we may estimate equal to a thousand square miles,—a fine sandstone approaching to clay being found at *a*, coarser grained sandstone at *b*, while conglomerate is discovered at *c*, the various parts shading into each other, so that no doubt can exist that the whole is geologically contemporaneous, that is, formed at the same geological epoch. It is clear that exactly the same circumstances have not obtained over the whole area during the deposition of the rock. As, in all probability, moving water has carried the component parts of the rock into the respective situations they now occupy, we might infer that the velocity of the transporting water had varied in the different situations; for it is clear that a velocity merely sufficient, all other things

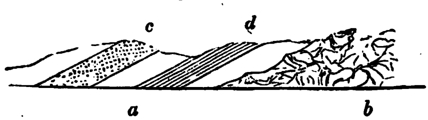
being equal, to carry the silt at *a* would be insufficient to move the coarser sand at *b*, while the larger fragments and pebbles at *c* could not be transported by the same force which would merely move the particles of sand at *b*. We might in fact infer that there was a greater intensity of moving power at *c* than at *a*, gradually decreasing from *c* to *a;* and consequently, if the same body of moving water has carried the parts of the rock to their present respective situations, that the velocity of such moving water decreased from *c* to *a*. By examining mere sandy clay, or even sand, the evidence as to the quarter whence the detritus was derived is not always satisfactory: with pebbles or fragments of rocks the case is, however, for the most part different; and we thus frequently obtain direct information as to the quarter whence they have been derived, such pebbles or fragments being portions of older rocks often visible in the district or country where the conglomerate exists. We will not here enter into the various ways in which moving water may distribute detritus, since the above remarks are merely intended to show that observations respecting the variations in structure of mechanical rocks possess considerable interest, and are highly important as respects theoretical geology.

When we find a rock crystalline and without organic remains in one part of its course, while other parts are not crystalline, perhaps even arenaceous, and replete with animal and vegetable exuviæ, it is clear that some circumstances have obtained in one part of the area not common to the whole; and if we desire to rise from a

view of the rocks themselves to the probable causes which have produced them, it is also evident that it is important to observe these differences with great care, since it is only by caution and duly weighing the evidence before us in all its bearings that we can approximate towards the truth.

In the above diagram (Fig. 10) we have supposed, for more easy illustration, that the rock was horizontal and uncovered by others: more frequently, however, rocks are not horizontal, and are covered by others over the larger portion of the areas which, we infer, are occupied by them. They are often tilted up, as in the vertical section beneath (Fig. 11), where we have sup-

Fig. 11.

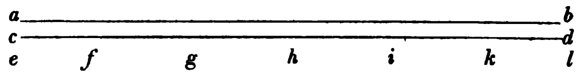


posed the stratified rock *a* to have been thrust up at one end by the protrusion of the igneous rock *b*; or they may have taken an inclination even equal to 30° or 40° when deposited.* In either of these cases variations (if there be any) in the structure of such beds as *c* or *d*, or of the general assemblage of beds composing the rock, can only be observed where the edges of the strata cut the surface of the country, or in natural or artificial vertical sections, such as ravines, quarries, &c. The lines in which such tilted or inclined beds cut the horizontal plane are termed those of *strike*

* See Researches in Theoretical Geology, p. 50.

or *direction* ; and by carefully observing the changes which take place in certain beds, or in the rocks generally of which they constitute the component parts, much valuable information may be obtained. To illustrate this, let us suppose that the lines *a b* and *c d*

Fig. 12.



represent the strike or direction of a highly inclined portion of the grauwacke of Southern Devon, where such changes are very common, and that the distance between the lines is about a mile. We may have an argillaceous slate at *e*, which passes into an arenaceous grauwacke at *f*, becoming a quartz rock at *g*, whence it again shades off to an arenaceous grauwacke at *h*, becoming more argillaceous at *i*, an argillaceous slate at *k*, and almost a roofing slate at *l*. From thus observing the various mineral conditions of the fossiliferous rocks, and noting the size of the respective areas in which the same mineral structure prevails, we obtain the comparative value of each condition, and consequently of the probable cause which may have produced it.

Although we should thus obtain information as to the variable forces of moving water by which abraded portions of pre-existing rocks have been deposited in new situations, and frequently of the quarters whence such detritus has been derived, as also of the relative amount of chemical products mixed with the mechanical rocks of the same geological epoch ; we should

not know that any other than the existing species of animals and plants had ever lived on the surface of our planet, or that there had been successive creations of animals and plants, called into existence and destroyed as new conditions arose, either over the earth's surface, or in areas of different magnitudes. The fossiliferous rocks afford us, by their organic contents, not only this, but also much collateral information of the highest interest, as well botanical and zoological, as geological. To the botanist and zoologist naturally belongs that careful investigation of organic remains which enables them to determine their true or highly probable place among those known created things which either have possessed or now possess life; while the geologist masses the information thus derived, and combines it with the probable causes that may have produced those conditions under which inorganic matter is presented to his attention on the surface of the earth.

For information respecting the various organic remains detected in the fossiliferous rocks, we must refer to those works which profess to give lists of such as have been hitherto described.* These lists are far more full than those unacquainted with the subject might suspect, and exhibit the great practical benefit of the division of labour; for though many of these exuviæ have been brought to light by those who may be strictly termed geologists, a large proportion have been col-

* For the organic remains found in the supracretaceous group (or tertiary rocks), consult Lyell's Principles of Geology, vol. iii. 1st and 2nd editions; and for those from the cretaceous to the grauwacke groups inclusive, De la Beche's Geological Manual, 3rd edition.

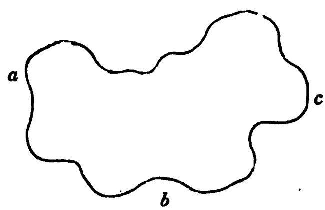
lected by persons whose acquaintance with geology, properly so called, has been limited.

It was once assumed that given assemblages of animal and vegetable exuviæ, discovered in particular rocks, would be found to characterise the mineral deposits of a given geological epoch, if not over the whole face of the globe, at least over very large portions of it. The distribution of animal and vegetable life over the surface of the earth being now so various, that no naturalist expects to find precisely the same animals and plants in localities far distant from each other, even when such localities are perfectly similar with respect to climate and other circumstances; it follows, that the supposition of given organic remains being always detected in rocks of the same geological epoch wherever such rocks may be found, is utterly at variance with the present distribution of animal and vegetable life over our planet.

Such hasty generalizations are common in the early history of most sciences, and can only be considered effectively mischievous when there is a determination to uphold them in spite of direct evidence of their unsoundness. It is more generally considered in the present day, that given organic remains are spread over larger areas, in contemporaneous rocks, in proportion to the geological antiquity of such rocks: that is, we should expect to find greater uniformity in the animal and vegetable exuviæ entombed in the grauwacke of distant localities than in the supracretaceous rocks of equally distant situations. Now it is remarkable that, as far as investigations have yet gone, there is much to support this hypothesis; but we must be careful in not

assuming it to be absolutely true until observations be greatly more multiplied than they are at present. If, however, we suppose it true, it can only be so to a certain extent; since we can scarcely imagine such complete uniformity of conditions over the globe, unmodified by local causes, as to afford exactly the same results everywhere. Moreover, we have direct evidence to adduce that the organic contents even of the more ancient rocks vary over minor areas. If the annexed

Fig. 13.



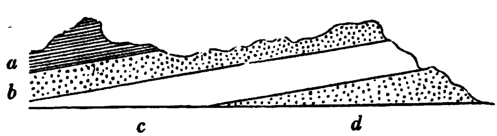
sketch (Fig. 13) represent an area of eight or ten thousand square miles occupied by some given rock, of the continuity of which, though frequently covered by more modern deposits, there exists no doubt, it rarely happens that the organic contents of such a rock would be found precisely the same at *a*, *b*, and *c*, respectively. It might so happen that marine exuviæ were alone detected at *a*, while remains indicative generally of the proximity of land were discovered at *b*, and little else than terrestrial plants were found at *c*. Independently of this change in the organic character of the deposit, we should probably also obtain a difference in its mineralogical character; the rock being per-

haps a limestone or highly calcareous at *a*, more argillaceous or clayey at *b*, while sandstones, shales, and even coal may constitute the mass at *c*.

The reader will have gathered from the preceding observations, that a combined view of the organic and mineralogical characters of the fossiliferous rocks is highly important, since we thence approximate towards a knowledge of the various causes which have attended their production. The question also of whether the ancient fossiliferous rocks are more constant in their organic characters over considerable areas than the modern, is also one of high geological interest, since, however little they may differ mineralogically from each other viewed in the mass, it is clear, if there be this difference in their organic character, there must have been some modifying circumstances at one epoch different from those at the other. It can only be by multiplied observations that this can be decided; and the power of contributing to solve this, as well as many other geological problems, is alike open to him whom these pages may induce to observe, as to those who have passed years in the study, and who, as geological pioneers, have smoothed many a rugged path for those who follow them.

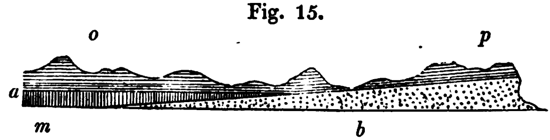
When fossiliferous rocks rest *conformably* upon each other, (that is, when, as in the annexed section, a series of

Fig. 14.



deposits rest upon an other in a manner which will not permit us to suppose that the lowest, *d*, has been heaved up, or otherwise disturbed, before the next above it, *c*, was formed, and so on with *b* and *a* in succession,) it is inferred that, in the situation where these rocks have been deposited, the organic exuviæ found in them are the remains of either animals or plants, as the case may be, which have succeeded each other in the same place in the order of the rocks themselves. It is not to be inferred, as has sometimes been done, that similar animals or plants succeeded each other over the whole surface of the globe; for, in the extension of a series of deposits such as that represented above (Fig. 14), in other directions other deposits may be discovered between the rocks of which it is composed, and yet, in the situation first observed, the rocks may rest as tabular masses conformably upon each other. Let us suppose that *a* and *b* (Fig. 15) represent the same rocks as *a* and *b*, Fig. 14, then *m* might be included between them at *o*, while at *p* they should appear strictly conformable, the rock *m* having *fined off*, as it is termed, in the horizontal distance between *o* and *p*;

Fig. 15.



that is, its vertical thickness has decreased by degrees, so that the horizontal extension of *m* would not be so great in this situation as that of *a* and *b*. It, however, by no means follows that *m* does not cover a greater

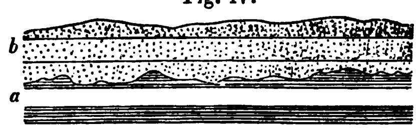
altogether, for it may readily do so, *a* and *b* fining between other rocks in other directions.

Vhen fossiliferous rocks rest *unconformably* upon ı other,—that is, when, as in the annexed section g. 16), a rock, *a*, rests upon the upturned edges of

Fig. 16.

beds *b*, *c*, *d*, *e*, *f*,—we cannot infer that the animals l plants whose exuviæ may be detected in *a* suc- ɜded those whose remains are discovered in *b*, since many rocks may have once existed above *b*, which have been carried away by *denudation*, as it is termed; that is, removed by the abrading power of moving water before *a* was formed: and if the angle be so considèrable as that represented above (Fig. 16), we should infer that the rocks *b*, *c*, *d*, *e*, *f*, were tilted up by violence before *a* was deposited. There is also another kind of superposition which may be termed *irregular*, even when the beds of two rocks in contact may, as masses, rest conformably on each other. If we find, as in the annexed section (Fig. 17), that the

Fig. 17.



upper surface of a fossiliferous rock, *a*, has been water-worn before another fossiliferous rock, *b*, was deposited

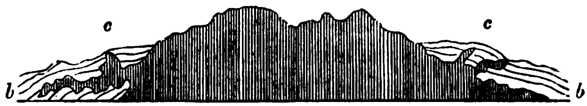
upon it, we have no evidence to show that the anima and plants existing when *a* was formed were succeed by those whose remains are detected in *b*; other inte vening deposits may have been thrown down, and sub sequently swept away, after the production of *a* an before the formation of *b*.

As this is not intended for an essay on the present state of geology, we shall now briefly notice the igneous rocks, and then proceed to our more immediate objec 'how to observe.' Those rocks are termed igne which we consider to have once been in a fluid from the action of heat upon them, and in that s o have overflowed, to have been injected among to have been propelled through, other rocks.

In volcanos we have direct evidence that liquid melted rock may be heaved out of the earth by forces acting beneath, and in that state flow over those channels which offer it the least resistance, thus forming the well-known *lava currents.* When also, from a change in the volcanic vent, great natural sections are afforded of a former crater, it is sometimes found that the melted rock has risen among the layers of ashes and cinders of former eruptions, cracks having been produced in the mass of such ashes and cinders, into which the fluid melted rock has risen.

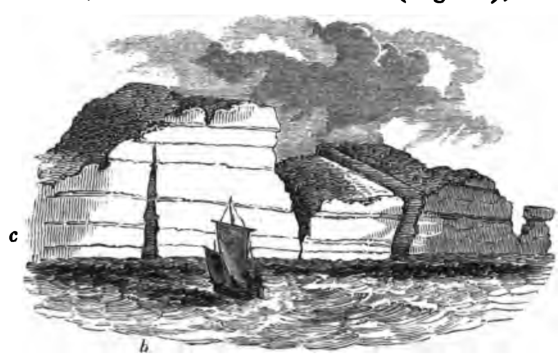
It is from similar facts being observable in the mode of occurrence of other rocks, known by the names of granite, greenstone, porphyry, &c., that we infer that they also have had an igneous origin, though not always under the same conditions as those observable in a modern volcano. When, for instance, a mass of granite, *a*, (Fig. 18,) sends out veins, *c c*, into a deci-

Fig. 18.



dedly stratified rock, *b b*, cutting the strata in various directions, the veins even including fragments of the rock, *b b*, we infer that the granite in question was once in a fluid melted state, was protruded through *b b* by forces acting beneath, and that a portion of the melted rock was forced into cracks at *c c*, thus forming the veins in the stratified rock *b b*, the beds of which were also upheaved at the same time. The inferences would be the same whether the protruded rock be granite, greenstone, porphyry, basalt, or others.

When, as in the annexed view (Fig. 19), a long

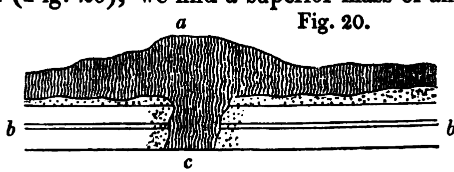


narrow mass of rock divides another, in the manner *a* does *c*, and this narrow mass of rock is composed of substances similar to those which constitute greenstone,

porphyry, or the like, we infer that the beds of the rock *c* were once continuous, that they have been subsequently broken, and that into the fractures liquid melted rock arose, filling the cavity formed by the crack. To these intruded masses of rock, consolidated as we now find them, the name of *dyke* is given, and they are known as greenstone, porphyry, basaltic, or other dykes, according to the kind of rock of which they are composed. Even when these masses of intruded rock do not rise to the surface of the land, and are only known to exist by natural or artificial sections, as at *b*, Fig. 19, they are still termed dykes.

We have sometimes good evidence to show that certain igneous rocks have, after traversing pre-existing beds, spread like a sheet over them, leaving masses, sometimes nearly tabular, at others more domed-shaped, above the pre-existing beds. When, as in the annexed section (Fig. 20), we find a superior mass of any given

Fig. 20.

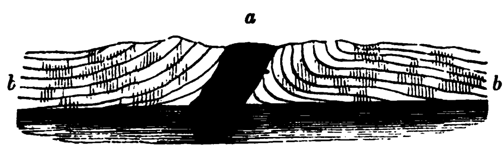


rock, *a*, such as greenstone, also cutting, as at *c*, through the rock *b b*, on which it reposes as a mass, we infer that a rent was made at *c*, in *b b*, and that through it the melted rock flowed upwards, and formed the upper portion or cap, *a*. If, supposing the rock *b b* a common fossiliferous limestone, we find those portions which are in contact with or near the greenstone to be crystalline, or *b b* being sandstone or shale greatly indurated, with even perhaps a tendency to

new arrangements in their component particles, we further infer that such alteration has been caused by the presence of the greenstone when liquid or intensely heated. Deposits which have suffered this change,—more particularly when such effects are observable on the large scale, and the distance from the once heated mass is measured by hundreds of feet and not by inches,—are termed *altered rocks*.

While the melted rock seems in some instances merely to have risen quietly in a crack or fissure, like any other liquid, to a level at which it can be supported by any proper force acting upon it; at others, as in Fig. 21, we find the two rocks so situated relatively to each other, that we can scarcely refuse to consider that the rise of the igneous rock

Fig. 21.



has been accompanied by force. If *a* (Fig. 21) be the intruded igneous rock, and *b b* a stratified deposit, then the beds near *a* being turned up on both sides of the dyke, we should infer that the substance of which *a* is composed had been thrown up with sufficient force to turn up the edges of the stratified rock, *b b*, on either side. It should however be observed, that the upturned character of beds on either side of dykes is more rare than a mere division of the stratified or other rock, without any mark of the violent intrusion of the matter of the dyke.

In some countries very considerable geological effects have been caused by the intrusion of igneous rocks among others of all geological ages, from the lowest known stratified rock to modern deposits inclusive. Sometimes they seem to have been thrown up in the manner of modern volcanos, accompanied by eruptions of ashes and cinders, either into the atmosphere, or some other relatively small superincumbent pressure; at others they appear to have been protruded, either in greater masses, or beneath great superincumbent pressure, producing a variety of effects which it would occupy too much space in this brief sketch to enumerate.

It was once supposed that granite was the fundamental rock upon which all others rested. Without entering into the theory which supposes the granitic to be that form of rock which was first produced if the mass of the earth were once in a state of igneous fusion, it may be considered that granite is more abundant, taken in the mass, among the inferior stratified or non-fossiliferous rocks, than among the fossiliferous class, particularly the more modern deposits of that class. We are not, however, to restrict granite to the lower fossiliferous rocks; on the contrary, we are not yet prepared to say how high up among that series it may be discovered, since it has been detected above the chalk at Weinböhla, and consequently it must have been ejected from beneath, in that situation, during the supracretaceous or tertiary epoch.

The mass of the igneous rocks appears to be composed, in variable proportions, of the silicates of alumina, magnesia, lime, potash and soda, with the occa-

sional and subordinate presence of a few other substances; those rocks being the most fusible in which silicate of lime is somewhat abundant, while the most refractory seem those in which silicate of magnesia prevails. Those in which the minerals named hornblende or augite (the latter probably only a modification of the former) abound, such as greenstones, basalts, and many lavas, are on that account more fusible than those in which mica prevails, such as many micaceous granites. Most granites are however refractory, particularly when quartz is abundant in them. Serpentine also is of difficult fusion; but those rocks in which the mineral named felspar prevails are not, in general, very refractory.

It has been considered that silica is more abundant, viewed in the mass, among the older than among the more modern igneous rocks, while lime (as a silicate) more abounds in the latter. Many of these rocks may never have been in a solid state before they were ejected upon the solid surface of the earth, while others may readily have been produced by fusion of the pre-existing solid rock, and then driven to the surface, in both cases, by sufficient forces acting beneath.

PART II.

As we should, when searching for the causes of any given effects, proceed, if possible, from the known to the unknown, it behoves us carefully to observe the effects of those causes which daily produce geological changes on the surface of the earth, and then, weighing all the circumstances under which the various rocks are presented to our attention, honestly to seek, without bias, to what extent they can explain the production of the different mineral masses which compose the exposed solid surface of the globe. If, after careful investigation, we find that the effects of those causes which are known now to act on and modify the world's surface prove insufficient, or only partially account for all the phenomena observed, we should endeavour to ascertain the extent to which they are insufficient, and then proceed to inquire how far the supposed greater intensity of similar causes may carry us. Should we still find many phenomena not satisfactorily explained, we must necessarily have recourse to various hypotheses founded on the known laws of nature, waiting until the progress of knowledge generally shall enable us to frame a theory in which the various parts shall be in harmony with each other, and with the whole taken collectively.

I. *Decomposition of rocks.*—There is a tendency in all rocks to decompose by the action of the atmosphere upon them, and to be afterwards carried by lines of

ing water to lower levels than they occupied prior decomposition, often into the sea, or other bodies of er, where they may be distributed in such a manner o produce new accumulations of mineral matter, or rocks as they are termed, in which the remains of ting animal or vegetable life may or may not be mbed, according to circumstances.

a. To appreciate the action of the atmosphere on given rocks, the observer should direct his attention to the amount of yearly or other change caused by it on masses of stone used for buildings, and which are supposed to have been taken from those situations in quarries where such masses have, to a great extent, been secured from atmospheric influence; carefully investigating whether the observed changes may have been caused by the chemical or mechanical action of the atmosphere, and of the substances accidentally contained in it;—that is, he should observe whether any of the component parts of the stone have united chemically with those of the air or the substances contained in it, or whether the external parts have been removed by the friction of water, by the freezing of water in the interstices of the stone, forcing the component particles asunder, or the like. Care should be taken to note the structure of the stone, ascertaining whether it be homogeneous, like compact limestone or marble, or composed of substances which, when exposed to the same causes of decomposition, resist them unequally, such as granite, conglomerates, and many sandstones.

Due attention should be paid to the variations of climate, noting carefully the aspect of the buildings, and if the same materials are differently decomposed in dif-

ferent aspects, endeavouring to show the reason such difference, such as the prevalence of driving r or of furious winds, more from one quarter than other. An antiquary, if he be a chemist, or call in aid of one, may in this manner afford valuable geol cal information, without neglecting his more pecu studies.

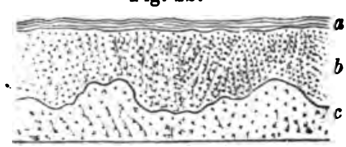
b. To estimate what have been the effects of dec position in surface rocks between the soil, as it is commonly termed, and the more solid parts of such rocks, the observer will have more difficulty; since he cannot know the amount of time during which they have been exposed to atmospheric influences; neither can he judge with precision as to the quantity of decomposed rock which may have been removed, nor of the variable character of the vegetation above, by which the decomposition has, according to circumstances, been more or less modified. Much may, however, be accomplished by careful observation.

Although on high mountains, where masses of rock are frequently exposed to the free action of the atmosphere, they are often greatly decomposed, we cannot estimate the depth to which a given rock has been *weathered*, as it is termed, so well as on lower grounds; for, on exposed mountains, the form of the surface is generally such that the decomposed parts are readily removed by the action of moving water to lower levels. We might indeed roughly estimate the amount of surface loss sustained by rocks in these situations, by means of the pinnacles and bosses of harder matter which still retain their places, if we could form anything like a just conception of the figure of the moun-

tains after they first occupied their present positions, and before the atmosphere acted upon them. Unfortunately, the stratification of mountain ranges is generally such that the rocks of which they are composed bear evidence of having been greatly fractured when forced into their present positions, and therefore the mountains, for aught we know to the contrary, may even have been more rugged and broken than we now find them.

In the lower lands, for instance on the top of broad-backed hills, where there would be a difficulty of removal by moving water, and where it has been carefully ascertained that transported substances have not been carried, we seem to arrive at more satisfactory conclusions. The observer should search for pits on central portions of the broadest part of such hills, and in them he will often detect good examples of decomposition. Perhaps he may find granite decomposed in

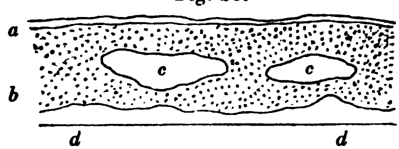
Fig. 22.



the manner represented in the annexed section (Fig. 22), in which *a* is the vegetable soil, as it is commonly called, *b* decomposed granite, and *c* granite in its solid form. In such a section as the above, he must be careful to ascertain that the particles of granite at *b* are exactly of the same kind as those at *c*, and that there can be no suspicion of their having been carried into their present position by moving water. Sometimes

he may find the granite decomposed so as to leave large rounded masses of solid granite surrounded by loose decomposed portions. The annexed illustration of this fact (Fig. 23) is taken from part of the road between Okehampton and Moreton Hampstead, in Devonshire;—*a* represents the vegetable soil, *b* decomposed granite, *c c* solid rounded masses of undecomposed granite included in the decomposed part, and *d d* solid granite. In such a section as this the observer should use great

Fig. 23.

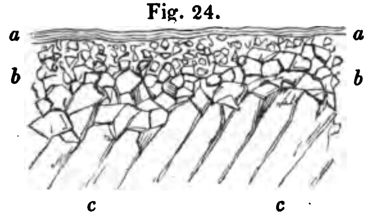


care, so that he may be certain that *c c* are not transported boulders of granite, included in smaller granitic gravel, *b*. Fortunately, in this case, he would be greatly assisted by the presence of large crystals of felspar disseminated through all parts of the rock, both decomposed and undecomposed, and which are beautifully preserved in their relative positions in the former. In the decomposed granite above noticed, the effect produced has been chiefly chemical, a change having been effected in the felspar through atmospheric agency.

Among a variety of hard rocks, the component parts of which do not readily combine with any portion of the air or of the water contained in it, and which are too compact to allow of any considerable absorption of water between their particles, considerable decomposition may yet be produced by the tendency of such

rocks to split into fragments when exposed to the influence of the atmosphere. The observer may often trace the breaking up of a compact limestone or hard sandstone in the manner represented in the annexed section (Fig. 24), in which *a* represents the vegetable

Fig. 24.



soil, *c c* a hard sandstone rock, such as some varieties of grauwacke, and *b b* fragments of the same rock, largest towards *c c*, and evidently constituting portions of the subjacent strata, while the upper fragments are smaller and more confusedly mixed, though still angular.

Probably much valuable information might be eventually obtained, if, when deep excavations are made for roads or other purposes, marks of a given depth and form were cut on the exposed surfaces, with the date attached; notes being made of the fresh condition of the rock when the mark was cut, and of other obvious circumstances, and the notes placed in some common place of security. Care should of course be taken to cut such marks only on such parts of rocks as were not previously exposed to the direct action of the atmosphere, and therefore as far beneath the decidedly *weathered* part as may be convenient, and at the same time secure from other injuries than those of atmospheric agents.

c. The observer must be careful, in his estimate of the amount of decomposition which rocks may sustain from the action of the atmosphere, duly to consider the power of vegetation to prevent, assist, or otherwise modify it, according to circumstances. Vegetation may prevent decomposition, by presenting a certain barrier to the effects of sudden frosts and thaws; assist the action of heavy rains by keeping the higher parts of rocks more permanently wet than they would otherwise be; or greatly modify it, by the various effects produced according to the kind of plants which may cover the land at given times: for a portion of country covered by forest-trees would be differently circumstanced, as regards the probable decomposition of the rocks of which it is formed, than when the same portion was either broken up for tillage or covered by pastures.

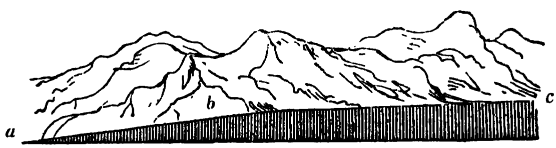
II. *Removal of parts of pre-existing rocks by moving water.*—The decomposed parts of rocks above noticed are necessarily of different sizes, according to the kind of solid rock whence they have been derived, and the circumstances to which their present condition is due. The angular fragments of hard limestone or sandstone, such as are sketched in Fig. 24, would offer greater resistance to any given force of moving water than a fine-grained decomposed sandstone: that is, supposing the same heavy storm of rain to fall equally on both, the loose sand of the decomposed sandstone might be washed away, while the large angular fragments of limestone might remain firm: or, supposing the two different kinds of decomposed rock to be equally exposed to the force of the same rivulet or

river, the one might be carried down the stream, while the other remained in its place.

a. When an observer is desirous of estimating the power of any particular stream or river to carry forward the detritus of pre-existing rocks, formed either by decomposition or by the abrasion of moving water, to be noticed hereafter, he must be careful to take several circumstances into consideration.

1st. The various slopes of the channel should engage his attention; for moving water carries detritus forward according to its velocity, and the latter neces-

Fig. 25.



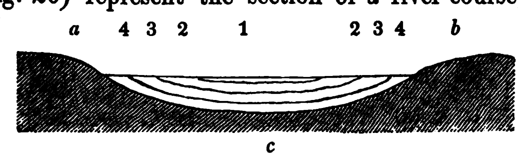
sarily increases with the amount of the slope: that is, if *a b* (Fig. 25) represent the exaggerated slope of a river in one place, and *b c* the slope of the same river in another, and the amount of water be neither increased nor diminished by tributary streams or diverging branches, the river will run much quicker at *a b* than it will at *c b*, and consequently smaller pebbles or finer sand can remain at the bottom of the latter than the former, because the force of the water would wash away much larger pebbles or sand at *a b* than it can at *c b*.

2ndly. The shape as well as the size of the detritus should be taken into account; for two fragments of the same rock, though exactly of the same size, or volume,

as it is termed, may be carried forward by different forces of moving water, if their shapes be different. A common angular fragment of a given rock, for instance, would not be moved at the bottom of a river, when the force of the water was only sufficient to roll on a piece of the same rock of a globular shape, though the two pieces should be of exactly the same size or volume.

3rdly. The relative weights, or specific gravities, of the different kinds of pebbles or fragments of rock should be duly considered; for the force of a river only sufficient to move one kind of pebble or fragment, would be unable to move others of greater weight or specific gravity, though their shape and size were the same. The stream of a river which could only move a ball of marble three inches in diameter, could not carry onwards an iron cannon-ball of the same size, supposing both placed under exactly the same circumstances.

If we knew the velocity of water required to move fragments of given size, shape, and weight, the observer would obviously only have to ascertain the velocity of any river he may have under examination, and he would at once obtain the kind of detritus which it could carry onwards. On this head, unfortunately, we possess little information which can be deemed satisfactory, and therefore direct experiments should be made to clear up the subject. We know, that if *a c b* (Fig. 26) represent the section of a river-course, the



greatest velocity will be at 1, and that it will decrease towards the sides and bottom, as may be represented by the layers of water, 2, 2 ; 3, 3 ; and 4, 4 ; but we do not know the law of this decrease, nor the amount of friction that we ought to have at the bottom and sides, when we have a known velocity of current in the middle (1), and when the depth of water, distance from the sides, and shape of the river-bed are also correctly ascertained. We should anticipate in such a section as that above (Fig. 26), that the friction of the same layer of water, next to the sides and bottom, would not be equal at the banks *a b*, and at the bottom *c*, since the weight of water would be greater at the latter than at the former.

b. The checks which a river may suffer in its course should be duly noted, such as lakes, patches of level land, and the like. Without this precaution it might be, and indeed has been, inferred, that all the pebbles found far down the course of all rivers have been swept onwards by the existing rivers. In some cases this may be true, but in many it is not so. Frequently, when a river takes its rise in high mountains, its course onwards is, though often rapid, interrupted by tracts of level country, or even lakes, where the larger detritus is arrested ; and yet pebbles derived from the rocks of the high mountains are found abundantly in the river-bed farther down than these obstacles, such pebbles having been brought down from the higher levels by pre-existing moving water. Thus Alpine pebbles in some of the rivers of Northern Italy could not have been carried into the plains of Lombardy by existing rivers, since the Lago Maggiore, the Lago di Como, and

others, necessarily stop the progress of the pebbles borne from the high Alps by the torrents which feed the lakes.

c. The proper time of estimating the transporting power of a river is during heavy floods, when fragments of rocks can be moved which would remain firm under ordinary circumstances. The observer should endeavour to separate the complicated effects of a flood in a cultivated country from each other, carefully weighing how much is due to the increased velocity of the river; to bodies of water ponded back by obstacles which give way before the pressure exerted upon them; to the transporting powers of sluices of water thus suddenly set in action; and to various other obvious circumstances:—in fact, endeavouring to ascertain what is really accomplished by the velocity of the water, by its weight and volume, or by the united action of its weight, velocity, and volume. He will thus avoid massing all the effects together, and by so doing attribute to one power that which is really due to another.

d. The transporting power of a current or stream of tide passing along a coast is, to a certain extent, the same as that of a broad river on the line of one of its banks. If, in imagination, we withdraw the other bank and substitute the open sea, moving in the direction of the river, we have a stream of tide or a current acting on a coast, and, of course, we have the same laws in force. The friction of the water on the land would retard its progress, and the power of the stream to remove loose matter would depend upon its velocity. Although the projecting headlands or capes would be most acted on, in the same manner as the obstacles to a

river's course, the action of a given velocity of water on a hundred miles of coast would be greatly less than on the bank of a river also one hundred miles long, all other circumstances being equal: for in a river, the stream of water, when thrown off by one bank, is again thrown on it by the other; whereas, on an open sea-coast, it rarely happens that within a moderate distance a stream of tide is thrown back again, when it is fairly driven off from the coast, by a cape or headland. It therefore follows that there would be less transporting action, viewed strictly with regard to equal velocity of water alone, on a line of sea-coast than on the bank of a river, all other circumstances being equal.

The proper time to study the effects of a current or stream of tide acting on a coast, is when the sea is perfectly calm,—that is, unruffled by waves. The observer should be careful to attend to this, as from want of due caution, the complicated action of the sea and atmosphere on coasts has often been attributed to the action of one cause only out of several causes. Streams of tide or currents undoubtedly run stronger when forced forward by strong winds, and due allowance should be made for the increased velocity in such cases; still, when we observe a coast at such times, we must carefully separate the action of the waves from that of the mere friction of the moving body of water.

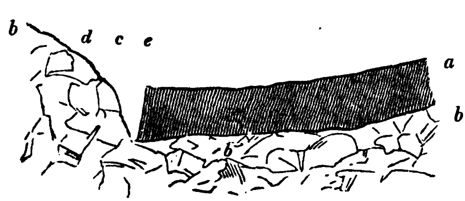
III. *Abrasion of rocks by moving water.*—It will be evident to those who observe a body of clear water driven against some of the softer rocks, that water has the power, when its volume and velocity are sufficient, to abrade rocks. This power is greatly increased when bodies of moving water, such as rivers, are charged with

detritus, since the friction is then greater. The observer should direct his attention to the various circumstances by which abrasion of this kind is effected.

a. If the moving water be a river, the amount of decomposition which a rock may have suffered, before acted on by the river, should be carefully estimated, so that the power of the river to abrade a given rock may not be over-estimated. As it is found that the decomposition of many rocks is greatly assisted by being kept alternately wet and dry, the observer should see whether the water of the river rises and falls in a manner sufficient to have an appreciable influence on the rocks washed by it.

b. In situations where we have reason to suppose that deep cuts or ravines have been formed by existing rivers, it is necessary to weigh well all the circumstances which may have attended such instances of abrasion. If a barrier, such as a lava-current, be suddenly thrown across a valley, the waters behind are necessarily sustained to the height of the lowest part of the obstacle thus opposed to their further progress down the valley. Now, when a section such as that annexed (Fig. 27) is presented to our attention, where

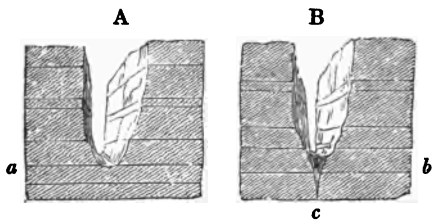
Fig. 27.



a lava-current, *a*, has flowed into a pre-existing valley of granite, *b b b*, and we find a ravine, *c*, through which a river flows, we must not too hastily conclude that the whole depth of the ravine has been produced by the erosive action of the river, since it may easily have happened that the lava-current, *a*, never completely filled up the valley, but that a space was left between the high part, *e*, of the lava, *a*, and the bank of granite, *d*. We might, *à priori*, infer that there would be an open space at *c*, resulting from the contraction of the mass of the lava-current, *a*, by cooling. Neither should we conclude, supposing the lava did rise to a proper height against the granite bank, *d*, that the same body of water would in the same time cut through the lava-current itself to the same depth, since, in the case of the section before us, the river in the ravine, *c*, would not only act with considerable advantage on the line of separation between the two rocks, but in all probability the outer side of the bank of granite, *d*, would have suffered by weathering, or the action of the atmosphere upon it, before the lava-current traversed the valley. When, therefore, the abrading power of the river was brought to act violently upon it, as would be the case under the circumstances above noticed, its destruction would not afford a satisfactory measure of the action of the same force of water on the solid granite during the same time.

c. Before the observer concludes that any ravine he may find has actually been cut by a river now flowing through it, he must be certain that the ravine is not the result of a great crack in the rocks which constitute its walls. When, therefore, he discovers a ravine which

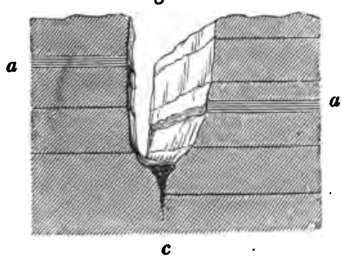
Fig. 28.



appears to have been cut by the abrading power of the river in it, he must carefully look for good evidence that it is not a crack, for such is not unfrequently the case. Let A and B (Fig. 28) represent two sectional views of two ravines, and let us suppose an observer placed in either endeavouring to ascertain their origin; he might conclude, from their general appearance alone, either that they were cut by the rivers in them, or were cracks, as best accorded with his preconceived opinions. To clear up this point, he must see if the two sides of the ravine are in any manner connected by a ridge or ledge of rocks. If he find one, he should in the next place ascertain whether any bed of rock, such as *a*, goes clearly across the river and is unbroken; because, if unbroken, he has direct evidence that the ravine is not due to a crack, but is an excavation in the body of the rock, as shown at A. If, on the contrary, he find no marked bed of rock extending continuously across the river, the evidence is uncertain; for the blocks, pebbles, or sand, as the case may be, in the river-course, may either cover such continuous beds, or the head of a crack such as that represented at *c* in B.

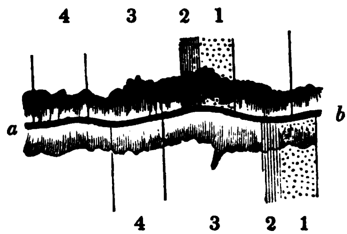
In the above sections (Fig. 28) we have made the rocks to correspond on either side of the valley, for the sake of more easy illustration. Should, however, the observer find the beds of rock on either side of the ravine so situated as to relative levels that they would not join, though horizontal, if prolonged towards each other; that is, if he discover, as in the annexed section (Fig. 29), that a horizontal and marked bed, *a*, was

Fig. 29.



higher on one side of the ravine than on the other,—he would at once perceive that the river has worked upon a crack, *c*, and that probably there has been compound action productive of the ravine — first, a crack in the body of the rock, and secondly, abrasion by running water along the line of the crack or fissure. Should he also find, supposing the beds of rock vertical, that they would not respectively meet if prolonged in the lines of the beds towards each other, he would infer that the body of rock had been dislocated, and that the river, if there be one, ran upon the line of dislocation. Let the annexed figure (Fig. 30) represent a map-sketch of a ravine, *a b*, through which a river flows, the various beds of rock on either side being vertical,

Fig. 30.



instead of being arranged in horizontal layers, as in Fig. 29. Should the observer find upon examination that a marked series of beds, 1, 2, 3, 4, would not meet if prolonged across the river, as represented above (Fig. 30), he will then know that the whole body of rock has been dislocated, and that the river runs in the line of fracture.

When, however, an observer is certain that any ravine is the higher part of a great crack or break in the continuity of the rocks on either side, he will still have to estimate the probable abrading effects of the river flowing upon such a crack or break, weighing well the general condition of the channel, the hardness of the rocks composing the walls of the ravine, and of the pebbles and pieces of rock forced down by the river, particularly during floods.

d. When there is reason to suppose that a lake has once existed in some principal line of valley, either from there having been a rise of the general bottom at one particular place, or that a lava-current has run across the valley, damming up the descending waters, and that the waters of the lake have been drained by gradually working down the barrier,—the observer must

study the probable height of the dam before it was cut through, in order to obtain an estimate of the body of water kept back, the amount of fall to the lower levels, the velocity of the descending waters, and the force of the abrading power. Let the annexed diagram (Fig. 31)

Fig. 31.

represent the longitudinal section of a lake, *a*, kept back in some principal valley by a lava-current, *b*, which has crossed it; then the height of *b* above *c* (the channel of the river below the obstacle *b*, and forming part of the former continuous channel *c d*,) would afford an estimate of the velocity with which the surplus waters of the lake, *a*, would rush towards *c*, and consequently of its abrading powers. This velocity, and consequently the abrading power, would decrease as *b* was gradually cut through, and the amount of fall became less.

e. The observer should not neglect the abrasion by minor streams and heavy falls of rain; for though it may not at first sight appear very considerable, yet, collectively viewed, small streams of water carry forward a great body of the smaller detritus to lower levels, where it is either accumulated in favourable situations, or transported onwards by the principal rivers, which throw much of it into the distributive power of the

sea. In the tropics, the observer will find the abrading power of a few hours' rain very striking, particularly in those favourable situations where there is no protection from the dense vegetation so common in such countries.

f. There has been scarcely any power more overrated by geologists, since attention has been paid to facts, than that of marine currents and streams of tide to abrade the coasts which they wash, and to excavate valleys in the bottoms beneath them. This seems mainly to have arisen from a want of correct observation, and sometimes from the absence of any definite idea of the power theoretically called into action. Hence have arisen the almost inconceivable errors respecting the geological effects produced by such agents. The attention of the observer has been called above to the transporting power of currents and streams of tide. To estimate the abrading effects of these powers, he should well weigh the velocity of the waters thus thrown into motion, the depth to which such velocity extends, and the retardation of the moving water as it approaches the coast or bottom, where, in point of fact, its abrading power begins. Duly to estimate the amount of abrading action, the observations should be made at the seasons and times when the currents or tides are in full force, and yet when the sea is perfectly calm. They should also be made at the junction of the water with the land, where alone any abrasion can take place. It may be almost needless to remark, that the proper time to estimate the abrading power of a tidal stream is during *high springs*, as they are technically termed, when the streams of tide run strongest.

IV. *Abrasion of coasts by waves.*—We may here

notice this power, which is the greatest land-abrading force with which we are acquainted, particularly when its effects are collectively considered.

a. Properly to estimate the effects of this power, the observer should be present on some exposed coast, such as that of the western part of Ireland, the Land's End, Cornwall, or among the Western Islands of Scotland, during a heavy gale from the westward, and mark the crash of a heavy Atlantic wave when it strikes the coast. The blow is sometimes so heavy that the rock will seem to tremble beneath his feet. He will generally find in such situations, that though the rocks are scooped and caverned into a thousand fantastic shapes, they are still hard rocks; for no others could continue long to resist the almost incessant action of such an abrading force. Having witnessed such a scene, he will be better able to appreciate the effects, even though the waves be far inferior in size, upon the softer rocks of other coasts.

b. The observer should carefully remark the direction of the prevalent winds, and the proportion of those which send the greatest waves, or seas as they are termed, on shore, in order that he may duly appreciate the loss of coast sustained in those directions where the force of the breakers is greatest and most incessant. Thus, on a coast on which western winds prevail, and there is a sufficient extent of open sea before it, we should expect to discover the greatest amount of destruction produced on points exposed to the westward, while rocks of equal hardness might be less abraded in places open to the eastward.

c. The attention of the observer should be directed

to the rise and fall of tide on tidal coasts, when estimating the abrading power of waves on such coasts; since a greater surface of rock, all other things being equal, is exposed where the rise and fall are great, than where they are small. Moreover, the rock is exposed to greater decomposition from being alternately wet and dry, in proportion to the surface so wetted and dried. It must not, however, be forgotten that coasts, where breakers reach the cliffs at high water, are frequently protected by beaches at low water; and that therefore they are removed from the abrading power of the waves during all the time that they break on the protecting beaches—a time which varies with the varying state of the tides and the state of the weather generally.

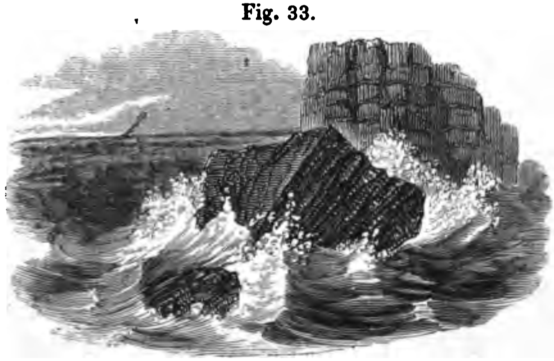
d. An observer will scarcely have long directed his attention to the abrading power of waves breaking on coasts, before he will discover many circumstances which modify the effects that would be otherwise produced. He will see that the abrasion of coasts is often greatly assisted by land-springs, as they are termed, that, as it were, shove the cliff into the power of the breakers by moistening a body of rock, which thus loses its cohesive powers and is launched in the direction of least resistance, or seaward. Other encroachments are made by the fall of masses of cliff undermined by the waves, the cohesive power of the rock not being equal to its weight or the action of gravity downwards. If, as in the annexed sketch (Fig. 32), a rock be even sufficiently cohesive in the mass as to admit of the considerable excavation there represented without falling, a time must come, if the breakers con-

tinue to work on in the same direction, when the weight of the superincumbent mass would be such that it must fall.

Fig. 32.

When, however, a great mass of cliff does fall, in the manner noticed above, the observer should direct his attention to its conservative influence. To appreciate this, he will consider the hardness of the rock, the position into which it has fallen, and its new power of

Fig. 33.



breaking the waves farther from the coast. If the mass of fallen rock be stratified, much will depend upon the face presented to the breakers; for if it fall so that the plane of the beds remains sloping seaward, as in Fig. 33, it will act as a well-contrived wall erected to defend the cliff: but if the beds should be exposed vertically

Fig. 34.

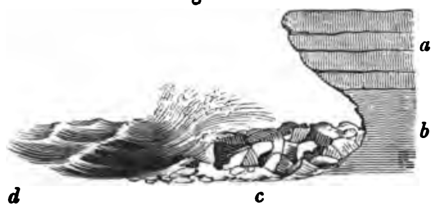
after the fall, as in Fig. 34, the future destruction of the mass would be far more rapid, and its conservative influence consequently less.

While on this subject, it may be noticed that incrustations by marine animals and seaweed tend greatly to protect the bases of cliffs on tidal coasts; and the observer should particularly direct his attention to the conservative influence of the *Balanus* in many situations.

e. The observer will sometimes find, when a soft rock forms the base of a cliff, and a hard rock the upper part of it, that the fall of masses of the upper part, in consequence of being undermined, will protect the

lower part from further destruction for a time depending on various circumstances. Let the annexed diagram (Fig. 35) represent the section of a cliff, the

Fig. 35.



upper part of which is composed of a hard rock, *a*, resting upon a softer rock, *b*; then the action of the sea, *d*, upon the cliff would undermine it, and cause the fall of masses of hard rock, *c*, which thus accumulating at its base, would protect the cliff according to the quantity of rock fallen, the size of the masses, and their hardness. The observer will find that such fallen portions of the harder parts of cliffs, whether they be fragments of harder superincumbent rocks, or indurated concretions of softer beds, greatly modify the abrading power of the breakers on a coast particularly during the lower states of the tide.

f. The actual power of breakers to triturate fragments of rocks according to their hardness, and consequently the relative powers of given rocks to resist such action, may often be roughly appreciated in beaches collected in favourable situations. Great care should, however, be taken to pay due attention to the circumstances attending the production of the beach, and more particularly to feel assured that pebbles, derived from any conglomerates which may exist in the vicinity, are not mixed with fragments of the same kind of rocks

detached in the present day from the cliffs on the existing line of coast. The same remark applies to rounded gravels brought down by neighbouring rivers, or washed out of the cliffs.

g. When an observer attempts a general estimate of the abrading power of waves on an extensive line of coast, he will do well to direct his attention, not only to the relative hardness of the rocks composing it, but also to the position of the beds, if the rocks be stratified. He will not fail to perceive how frequently lines of coast, under otherwise equal circumstances, depend on the direction and dip of the strata. Their position with respect to the force of the sea is necessarily important; for if a series of beds such as those in the annexed sketch (Fig. 36) dip seaward, the action of the sea

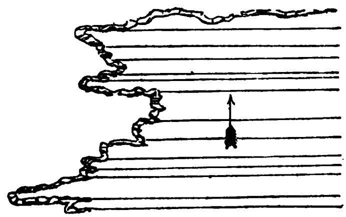
Fig. 36.

upon them can be but relatively trifling, since the return of one wave down the slope diminishes the force of the next falling on the coast, and what remains of it is gradually expended by running up the slope, in which there is no projecting part to offer sudden resistance to the course of the wave. The positions in which the edges of the beds of any given rock are exposed to the

Fig. 37.

N

W



action of the breakers, are those where the loss by abrasion is greatest. Let us suppose that the annexed sketch (Fig. 37) represents a line of coast exposed to the North and West, and that the abrading power of the waves is equal from both points; then the real effect produced will depend upon the resisting powers of the rocks themselves. If we now suppose the country composed of any given rock, such as grauwacke, and the direction or strike of the beds from E. to W., and their dip about 45° to the N.; then the resisting powers of the rocks will be great on the north coast, since the beds shelve seaward in that direction, while the same rocks will be exposed to much abrasion on the west coast, since the edges of the beds are exposed in that direction, and numerous indentations will be the result.

Even in cases where beds of rocks on coasts shelve seaward, the abrading power of the breakers is still frequently apparent. The sea often works upon the land by means of the cleavage fissures or joints of the rocks themselves, or on the fractures caused by faults: nevertheless, the protecting power of strata which do thus shelve is always sufficiently observable.

h. The observer would always do well to inquire from aged fishermen and others, on coasts where he suspects the loss of land has been great within the

memory of man, how much has gone within their recollection ; not contenting himself with loose generalities, but compelling specific answers as to the actual quantity lost, with their recollection of what was done with such portions before they were removed by the action of the sea. The author has sometimes been told of vast losses in this manner, which have subsequently turned out to be relatively trifling ; while, on the other hand, they have sometimes been underrated. Little dependance can be placed on old maps of coasts, which are for the most part exceedingly inaccurate ; indeed, there would be no difficulty in producing those which would, when compared with a modern good survey, show an increase of half or three quarters of a mile on a coast where, in point of fact, there had been considerable loss.

V. *Mechanical deposit of detritus in river-courses and on plains.*—From the various causes above noticed, a large collective amount of detritus, or variously sized portions of pre-existing rocks detached from them by decomposition or abrasion, is either mechanically suspended in, or propelled forward by, moving waters, from which it is deposited under favourable circumstances.

a. Fully to appreciate the distance to which the various kinds of detritus may be carried by moving water, until they be deposited, an observer should direct his attention to the quantity and kind which can merely be pushed forwards by a given velocity of such water, acting on the bottom or sides over or against which it may flow, and to the quantity and kind the same velocity may keep mechanically suspended at the same time. In the former case, the friction of the

water on the bottom or sides is the cause of the forward motion of such detritus; while, in the latter, the particles of detritus are, as it were, shaken up among the particles of water by sufficient velocity and agitation, upon the same principle that fine silty matter, placed in a bowl of water, is shaken up into the water by agitation. As the silty matter remains mechanically suspended in the water of the bowl as long as the necessary agitation continues, so does rock detritus continue mechanically suspended in larger bodies of water until the agitation be insufficient to keep it so suspended, when a settlement takes place.

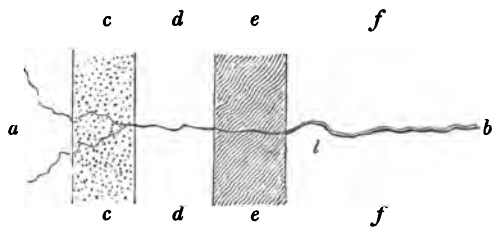
b. The observer will not fail to remark, that in torrents rendered turbid by the wash of detritus into them, from heavy falls of rain or other causes, the water is in a constant state of agitation, and that silt and sand are only deposited in those places where this agitation is insufficient to keep them mechanically suspended. Moreover, he will see that upon the amount of velocity and agitation depends the size of the detritus which can be carried forwards. Some of this detritus is mechanically suspended in the torrent, while other portions, necessarily the largest, are pushed forwards by its friction against the bottom and sides. Two causes therefore are in operation at the same time, both tending to carry portions of pre-existing rocks to lower levels.

c. When an observer detects detritus of a particular kind disseminated through moving water, he must not too hastily conclude that the velocity with which the water is then flowing is sufficient to keep such detritus permanently suspended; that is, that such detritus would continue to be mechanically suspended so long

as such velocity remained the same. Detritus disseminated in still water experiences a mechanical difficulty in descending to the bottom in proportion to its fineness. The same law holds good in moving water; though probably such difficulty is increased in proportion as the velocity of the suspending water increases, until finally the velocity be sufficient to keep it mechanically suspended. There will, however, evidently be a point where the power of mechanical suspension from agitation ceases, and the power of settlement begins, the latter increasing as the moving water is gradually brought to rest.

d. Attention should be directed to the appearances of deposits caused by the various modes in which they may be effected. A deposit resulting from the pushing process, itself arising from the friction of moving water on the bottom or sides over or against which it may pass, would necessarily present a different appearance from one gradually formed by the settlement of mud, silt, or sand in still water. The pushing process would continue as long as the pushing power of the water continued,—or, in other words, as long as the moving water possessed sufficient velocity and weight. An observer may estimate the power of a river to push detritus along its course by examining the pebbles and sands in its bed, due regard being paid to various circumstances previously noticed, and a knowledge having been obtained of the various rocks existing in the course of the river. Let the annexed sketch (Fig. 38) represent the course of a river, *a b*, through a country composed of marked rocks, *c c*, *d d*, *e e*, into a low country, *f f*, where its movement becomes sluggish; and let the fall of the river-bed from *a* to the low country

Fig. 38.



be sufficient to produce a stream capable of pushing forwards pebbles of the size of an egg, where its full force can be directed against them. If the river be capable of forcing such pebbles onwards, it follows that, all other circumstances being equal, it can drive forwards those of less size, and that finally there will be a size which the velocity of the river can keep mechanically suspended in its waters. There will necessarily be a deposit of the detritus pushed forward wherever sufficient obstacles present themselves; and as the river would vary in its power to push detritus onwards according to the quantity of water in it, such deposits would possess an irregular character somewhat resembling the annexed section (Fig. 39), depending on small shifts in the directions and force of the propelling current.

Fig. 39.

In the sketch (Fig. 38) we have supposed the river capable of propelling pebbles to the commencement of

the low ground, *f f*; therefore the observer would look for irregular accumulations of gravel and sand at *l*, where the more level channel of the river commences, and the ability of the moving water to shove pebbles onwards ceases. He would not, however, expect the finer silt and mud to be also there accumulated; since, though the power to keep such detrital matter mechanically suspended would be gradually lost by the river, the time required for the settlement, particularly of the finer parts, might be such that the whole body of water may continue to move down through the lowland in a turbid and discoloured condition, slowly parting with the detrital matter disseminated through it; the agitation of the moving water being frequently such as to keep the mud and silt suspended until the whole be stopped by a body of still water, such as a lake or the sea.

e. A deposit of transported detritus could not be otherwise than produced along the line of a river under the circumstances above noticed; and hence we should expect, unless such deposits were cut up by floods and thus carried still farther forwards, that the bed of the river would be raised. To this circumstance the attention of an observer should be directed. For the most part, the power of a stream to keep its channel clean, and even to work it deeper, after the principal hollows are filled up, is obvious where it runs with rapidity; but where it changes from rapid to slow and sluggish, it will be often found to raise its bed by the accumulation of detritus which has been gradually *shoved* from the higher levels downwards. In broad plains much alluvial matter seems to have been collected

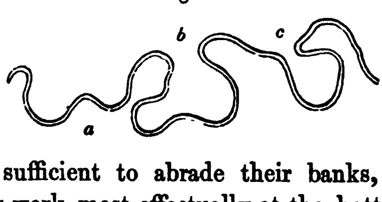
by the raising of channels, and the tendency of the rivers to quit such raised beds and flow in lower levels, which are in their turn also raised, so that eventually the whole plain acquires a certain additional increase in height. It follows, that if, in such rivers as tend to raise their beds, artificial embankments be formed, the rise of bed will be more rapid than where the detritus can, during floods, be forced off on either side upon the lower levels. Now this is found to be matter of fact, and the traveller in many parts of Italy will be more particularly struck with it, because the plains of that country have been long under cultivation, and it has been necessary to protect such lands for an equal length of time from the ravages of the rivers which flow among them. This having been accomplished by continuing to raise the embankments in proportion as the river raised its bed, the road across some of these rivers traverses a corresponding line of elevated ground.

f. It must not be supposed that the sands, clays, and gravels, often termed alluvial, of all great plains, have been produced by the deposition of detritus brought down from higher levels by rivers; because, from the organic remains detected in such sands, clays, and gravel, we have often evidence that some have been produced beneath the waters of a sea, and others apparently in those of lakes. Moreover, fragments of rocks contained in the gravels of level lands are sometimes of kinds and magnitudes which could not have been drifted into their present situations by existing rivers. An observer therefore, before he concludes that the sands, clays, or gravels of any given plain have been accumulated from detritus deposited by existing rivers, should

carefully search for sections of the level land, either along the banks of the river itself, in the gulley water-courses which communicate with it, or in artificial excavations, such as wells and the like. He should in such situations search very carefully for organic remains, because frequently the kind found will afford him valuable information. He should also search among the pebbles of gravel beds, and see whether there are any derived from rocks not comprised within the present drainage of the country, by the existing rivers or their tributaries, to the spot examined. Even when he finds no other pebbles than those of rocks comprised within such drainage, he should carefully consider whether they could, from their magnitude or other circumstances, have been brought down to their present localities by any force of water which could reasonably be attributed to the existing rivers even during extraordinary floods.

g. There are few persons, probably, who have not remarked that rivers are greatly disposed to serpentine in level countries. A small obstacle seems readily to have diverted their courses when they first flowed in such situations. If the velocity of such serpentine

Fig. 40.

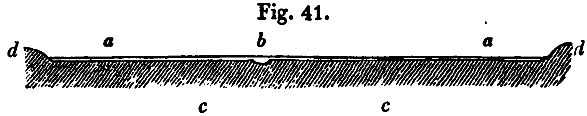


rivers be sufficient to abrade their banks, they will necessarily work most effectually at the bottom of each bend, because there they meet with the greatest obsta-

cles to their onward course. Hence, if two bends are opposite to each other, as those of the river in the annexed sketch (Fig. 40) are at *a*, *b*, and *c*, they will tend to approximate to each other and finally to meet, when the channel of the river will be shortened by the amount of the bend. Changes of bed thus produced are, as is well known, common in the Mississippi, and must of necessity take place in any river where similar circumstances occur. By this process, considerable shifts of the detritus brought down by a river may be effected; and consequently, if there be any resulting deposit over a plain, it will be of an exceedingly irregular character.

h. When an observer sees a tract of level country flooded, or covered by the turbid waters of a river which has overflowed its banks, he should endeavour to appreciate the quantity of solid matter that would be added to the land, if the waters subsided so gradually as to permit the deposition of a large portion of the fine detritus disseminated through them. He may estimate the amount of solid matter thus held in suspension over a given area at any one time, by procuring some of the water in a vessel holding a given quantity,—a cubic foot for instance,—and after allowing the turbid water to clear itself by precipitation, by ascertaining the relative amount of the precipitate; so that by calculating the depth of the water over the flooded area, and the size of the area itself, he would obtain the amount of solid matter which *might* be added to a particular

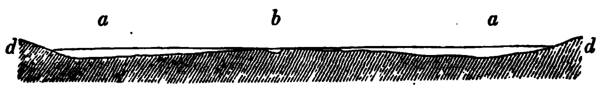
Fig. 41.



piece of lowland country by any one flood. If the annexed section (Fig. 41) represent that of a level plain, *c c*, through which a river, *b*, passes, which has overflowed its banks in consequence of heavy rains, and spread out in the directions *a* and *a*, until it is stopped at the rising lands, *d d;* then, during the subsidence of the river-waters generally, it can scarcely happen but that a considerable portion of the turbid waters would find their way back into the river-course, *b*, and thus, admitting a small general deposit while the whole body of water was kept up, the flat land would not gain the addition of precipitated detritus which might at first sight be supposed.

The case will, however, be different, if, as in the

Fig. 42.

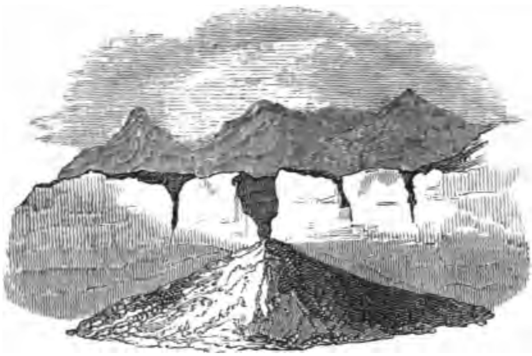


annexed section (Fig. 42), a river, *b*, has raised its bed, so that there are large tracts of country at a lower level on either side of it. If a flood takes place in such a river, spreading over the adjoining country in a sheet of turbid water, *a a*, until stopped by rising lands, *d d*, then *all* the solid matter disseminated in such sheets of turbid water, below the level of the river-banks, would be deposited on the lands which they cover; and there may be an additional quantity obtained, if, when the whole country was flooded, the level of the general sheet of water was above that of the river-banks; since, before that portion which rose above the level of the banks found its way back to the river-course, sediment may have been precipitated from it.

Viewing this difference in the cases noticed, an observer will do well to ascertain whether or not the bed, or rather the banks of a river in a plain, do or do not rise above the level country generally. This is of necessity a delicate operation when plains are extensive; but it should be strictly attended to when we wish to estimate the amount of fine solid matter which may thus be spread over extensive tracts of low lands, such as the plains of India.

i. Before we pass on to another subject, it may be necessary to call the attention of the observer to those accumulations of detritus which are often brought by transverse tributaries into the main rivers of mountainous districts. If the tributary deliver itself with its full force at the same level, or nearly the same level, into the main stream, then there is generally no great accumulation of detritus, except under extraordinary circumstances, such as a heavy fall of rain in the country drained by the tributary, which is not felt higher up the main stream; for then, by the increased transporting power of the tributary, a body of detritus may be driven into the main river which it cannot remove, so that in extreme cases the latter may even be dammed up for a time, and a debacle be the consequence, when the main river overcomes the resistance opposed to it, and drives the loose detritus before it. When, however, as in the annexed sketch (Fig. 43), the tributary comes through a lateral gorge, at a level considerably above the main river, it tends to deposit the detritus it may force forward in the form of a half cone, or one divided perpendicularly to its base. This form it will retain if the main stream be not so close as to work upon its base and carry it away; and in favourable situations, such

Fig. 43.



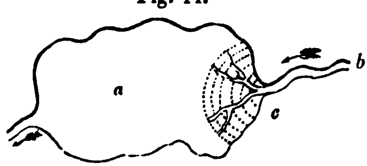
as in some parts of the Alps, cottages and cultivation will be seen in those parts of the mound where the more or less divided streams of the tributary do not rush furiously onwards to the lower levels. An observer will do well to direct his attention to the mode in which angular masses of rock, both great and small, are mixed up, pell mell, with clay, sands, rounded pebbles, fragments of trees, &c. in these accumulations, which are sometimes considerable; since it may assist him when he comes to consider the probable origin of various kinds of conglomerates among the older rocks.

VI. *Deposit of detritus in lakes and seas.*—As the greater number of rocks divided into beds, and hence termed stratified, are supposed to have been formed by the deposition of sediment beneath the waters of lakes and seas, it becomes important carefully to observe the manner in which rock detritus brought by rivers, or derived directly from coasts, is thrown down on the bottoms of the present lakes and seas. In such cases

as are concealed from sight, and which unfortunately are somewhat numerous, the observer should endeavour to approximate as nearly as possible to the truth, by carefully weighing the various circumstances which may produce the deposit of sediment in such situations, due regard being paid to the operation of local modifying causes.

a. An observer may derive much information as to the mode in which detritus is pushed forwards by rivers into bodies of still, or comparatively still, water, by watching sand carried down by a rivulet into a pool of still water, where the sand is no longer forced onwards, and where it consequently accumulates. It is obvious that similar effects may be obtained by casting loose sand into a stream of water, the velocity of which enables it to push such sand forwards to a still pool into which the rivulet delivers itself. It will in either case be found that little heaps of sand are formed where the rivulet enters the pool, and that the accumulated sands tend to arrange themselves so as to constitute little truncated semicones, if we may be allowed the expression, on the fan-shaped tops of which the channels, over which the moving water pushes the grains of sand, are continually shifting. If, in the accompanying sketch (Fig. 44),

Fig. 44.

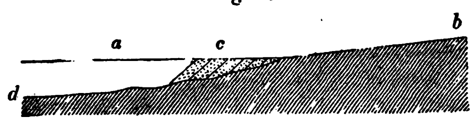


a represent a pool of still water into which a rivulet, *b*, pushes forward sand, then such sand will be found to

accumulate at *c*, falling down into the pool, *a*, in such a manner that a little truncated semi-conical heap of sand is produced, which increases superficially, as is shown by the concentric lines at *c*.

If now the observer direct his attention to the vertical manner in which the grains of sand are accumulated, he will find that they arrange themselves as in the annexed section (Fig. 45), in which *a* represents the

Fig. 45.



surface of the pool, *d* its bottom, *b* the slope of the rivulet pushing forward the grains of sand, and *c* successive coats of sand formed by the grains falling over into still water, such grains supporting each other at angles of 45° or less, according to circumstances, in the same manner as may be seen in any rubbish-heap from the top of which rubbish is continually thrown over. The velocity with which the grains of sand are forced forwards by the rivulet will cause the successive coatings of sand to be inclined at a less angle at first than afterwards; for as the little heap accumulates, and its flat top becomes extended, the force of the stream will, from the division of the water into minor parts and the diminished inclination of the channels, become less where the grains of sand fall into the pool, and consequently they will be pushed with less force to the edge and fall more lightly over. It will also happen that the little stones, which the stream may be able to shove forwards during the production of the first layers of the little

heap, the rivulet may be unable to push over the flat top of the latter after it has become somewhat extended into the pool.

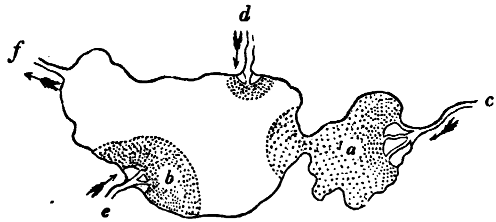
If, when the heap of sand has been accumulated to the extent desired, the water of the rivulet be turned off on one side, and the pool pumped out so that the form of the little heap of accumulated sand remain uninjured, the observer will be enabled to study it. Let him now carefully divide the heap perpendicularly with a sharp spade or other cutting instrument, and he will obtain a section that will enable him to examine the mode in which it has been formed. This, however, he will not in general very clearly see if the sand be of one kind and colour; but if he will throw, as the author of these pages has done, variously coloured sands, and of differently sized grains, into a rivulet which could move them onwards to the experimental pool, care being taken that one colour and kind is fairly washed down before others are thrown in, he will very readily see the inclined positions of the resulting concentric layers. If the experiment be conducted so that the water in the rivulet be increased and diminished at pleasure, thus enabling it to carry forward larger detritus at one time than at another, sometimes even rendering the waters turbid and allowing a sedimentary settlement in the pool, the observer will obtain a great variety of results, the importance of which he will speedily see.

b. The mode in which rock detritus, shoved along the bottoms of rivers by the force of their currents, and subsequently pushed into lakes or seas, is accumulated in such situations, is precisely the same in principle as

the accumulation of sand in the manner above noticed. From the different magnitudes of the objects, the effects are greatly more striking in the one case than in the other, and the modifying causes are more apparent; yet the principle remains the same, and layer beyond layer is added to the larger mass in the same way as they were added to the smaller. The stones or sands, as the case may be, are shoved to the edges of the greater accumulation of loose materials, where, losing the support which they had previously received from the river-channels, they fall over and arrange themselves according to the laws which govern bodies under such circumstances.

c. If an observer direct his attention to the manner in which detritus is protruded into any great lake, such as those of North America, Switzerland, or Northern Italy, it will rarely happen but that he will find considerable variation both in the kind and in the mode of the deposit thus thrust by the different rivers and torrents into the lake. Hitherto we have only considered the friction of rivers on their channels, by which detritus is shoved forward in still water: it is, however, necessary to call the attention of the reader to the detritus which is either held in mechanical suspension by the agitation of the river water, or which is in the act of falling through it to the bottom when discharged into the lake. Let us suppose that the accompanying sketch (Fig. 46) represents a lake divided into two unequal portions by the approach of the opposite shores to each other in one place, and that an observer is desirous of appreciating the effects produced by the deposition of detritus brought down by the feeding-

Fig. 46.



rivers, *c*, *d*, and *e*. He will in the first place take into account the velocities of the respective rivers, and this he may roughly estimate by the slopes of their respective channels, due attention being paid to the relative quantity of water in each; he will then proceed to consider the relative permanence of given quantities of water in each river. In the case before us, let *c* be the main feeding-river, flowing from a relatively considerable distance, always pouring a considerable body of water into the lake, the surplus waters of which escape by the discharging outlet, *f*; and let *d* and *e* be the channels of two torrents which occasionally descend from mountain heights on either side of the lake with considerable force, while at other times they contain little water.

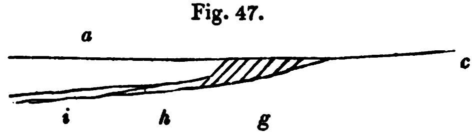
Let us further suppose that the waters of the river *c* are generally turbid, like those of the glacier waters of the Alps, though they vary considerably in quantity according to circumstances, as is usually the case with most rivers; so that *c* has the power of transporting and pushing detritus unequally. It will be clear that the effects produced by the river *c* will be more constant than those caused by the torrents *d* and *e*, though

it may not send so great a quantity of solid matter into the lake in a given time as is done by the torrents *d* and *e*. This will however depend upon a variety of local circumstances. We will suppose, for the sake of illustration, that the collective amount of detritus thrown into the lake (Fig. 46) by the two torrents *d* and *e* is equal to that carried forward by the river *c*.

With these data before us, let us see the manner in which we may estimate the effects produced. If we were examining any given lake at present, one in which the filling process had been going on for a great length of time, we should take the present relative depths into account, particularly if desirous of forming any estimate of the time required to fill up the lake by means of the detritus now borne or thrust into it. To form, however, a clearer idea of the kind and distribution of the deposits that would be produced according to the above-noticed data, we will consider the commencement of the filling process, and, for greater simplicity, suppose the depth of the lake nearly uniform throughout, though of course the primitive form of the lake-basin would influence the products. The river *c* would accumulate the detritus it pushes along its channel by friction, in the form previously noticed, while at the same time it will pour a body of turbid water into the still waters of the lake. The force of the former is checked by the latter, and the turbid water, being heavier than that of *fresh-water* lakes, sinks in clouds towards the bottom, as may be well seen where the Rhone enters the Lake of Geneva, and in various other similar situations. The velocity with which the turbid water enters the lake carries it to various proportionate

distances; but its motion being finally checked, the sediment is deposited. As the detritus would be carried farthest forwards in proportion to its fineness, we should obtain complicated effects, something like those represented in the annexed section (Fig. 47), where *c* being

Fig. 47.



the river, and *a* the surface of the lake, *g* would be the detritus accumulated by the pushing process; *h* and *i*, deposits from the turbid waters checked in their motion by the lake, the sediment being sandy at *h* and muddy at *i*, because the larger suspended detritus would sooner fall from the checked waters than the finer matter. It will be obvious that, after a time, the detritus, merely pushed forward, will accumulate over the sediment thrown down from the turbid water, and that therefore inclined beds of coarse detritus would cover the nearly horizontal accumulations of fine sediment. It would take up too much of our space to enter into a detail of the complicated effects which might be produced; but many can readily be conceived.

To return to the sketch of the lake (Fig. 46). Let us suppose, that from the complicated effects noticed above, the general resulting mass of sediment, deposited or pushed forward by *c*, occupies the dotted area *a*, covering the whole of the small lake and extending a short distance into the larger lake. We have now to consider the effects produced by the torrents, *d* and *e*; and the case may be rendered more illustrative, if we consider that,

from the nature of the rocks traversed by the respective torrents, fragments of hard rock only are shoved forwards by *d*, while much earthy matter and soft rock, easily comminuted by friction, is mixed with the harder fragments thrust into the lake by *e*. If little earthy matter be carried forward by *d*, the accumulation where the torrent enters the lake would form little else than a semi-conical heap of fragments, which would become truncated in the manner formerly noticed, as layer accumulated above layer, and the bottom of the lake would be little covered from this cause beyond the heap of fragments. With the torrent *e* the effects would be somewhat different: we should obtain the heap of fragments as in the other case, but it would be mixed with softer matter, and a quantity of turbid water would be poured into the lake, from whence there would be a sedimentary deposit as in the case of *c*.

Thus we ultimately obtain a heap of hard, and, in all probability, angular, fragments at *d*; a similar heap, though mixed in a more confused manner with softer substances, at *e*, to which is added a mass of sandy and muddy sediment, that we may suppose, for illustration, covers the dotted area *b*; and an accumulation of pushed fragments, in all probability more or less rounded, if much rolled, and of finer sedimentary deposit, at *a*. If we now take into consideration, that the deposits would be greatly modified by variations in the quantity of water in the rivers and torrents at different times, particularly in *c*, we have a very complicated general deposit, which would still undergo modifications as the filling process continued; so that eventually if the lake were filled up, and any great geological change produced various sections

of its solid contents, there would be very little mineralogical resemblances in its different parts. It must not however be forgotten, that the greater the predominance of any one cause, the more would the general resulting effects resemble each other. For instance, the Rhone is the principal filling agent in activity in the Lake of Geneva; and if, in imagination, we contemplate the whole lake filled up, sedimentary matter, derived from the glacier waters of the Rhone, would be the characteristic deposit.

d. The principle on which detritus is pushed by rivers into the sea is the same as that on which it is forced into fresh water; but there are several modifying circumstances which the observer should be careful to take into account when estimating the effects thus produced. The various protrusions of deposited detrital matter known by the general name of *deltas*, such as those of the Nile, Indus, Ganges, &c., consist both of detritus forced forward by the friction of the river-waters on their channels, and of other detritus thrown down from mechanical suspension in the same waters. One main point to be taken into consideration is, that the specific gravity of sea-water is greater than that of fresh water,—that is, it is heavier; and hence it happens that turbid river-water, unless it be considerably charged with mechanically suspended detrital matter, is still lighter than sea-water, and will flow over it to a distance proportionate to the velocity and volume of the river discharging itself into the sea, all other things being equal.

Instead, therefore, of the turbid river-waters falling down in clouds, as happens in the case of turbid rivers

discharging themselves into fresh-water lakes, they would have a tendency to float upon the sea-waters, and to be carried, either by the current produced by the river, or by tides and other causes, to a greater distance than they would be in fresh-water lakes, however large these may be. From this cause, a more general and uniform deposit may be effected beneath the sea than beneath fresh waters, from the same quantity and quality of turbid water discharged with equal velocity into them. The observer must, however, here again take modifying circumstances into account. As far as the mere striking of a body of river-water against a still fluid is concerned, it will necessarily receive the greatest check from the heaviest or most dense; and hence any given river would be more checked by rushing into the sea than into fresh-water, if it were not that in the former case it ran over it, while in the other it ran into it, and therefore received the greatest check, on the same principle that a river is more retarded by running into sands than by flowing over them.

The different density of the river from the sea-water should also be attended to on another account. The greater the density of the fluid, the greater would be the difficulty of detritus of the same weight, size, and shape passing through it. Hence the same kind of detritus would take a greater length of time in passing through sea than fresh water, both being of the same depth, and therefore would be a longer time exposed to the chances of movement in the one case than in the other. It also follows, that detritus, which would just settle when the velocity of a turbid river was checked by flowing into a body of fresh water, would not so imme-

diately settle from a turbid river discharging itself into the sea. In the first place, the river would not experience the same amount of check; and, in the second, the detritus would afterwards have to pass through a denser medium to the bottom, even in the case where the river and sea waters were somewhat mixed. These hints will be sufficient to direct the attention of the observer to several modifying circumstances, and others springing from them will readily present themselves to his consideration.

An observer desirous of making direct experiments on the depth to which the turbid waters of rivers may extend, either near their embouchures, or flowing some distance out to sea, should procure water from different depths by one of those instruments contrived for such purposes, and carefully ascertain their relative specific gravities, in order that he may not attribute the presence of merely discoloured surface-water at a distance from land to a wrong cause. He should also take the temperatures of the waters at different depths, as these also may assist him in estimating the relative densities of the waters. By these means Captain Sabine came to the conclusion that the discoloured waters of the Amazons flowed over the ocean to the distance of three hundred miles from its embouchure.

e. It will be evident that if there be any great movements in the waters of the sea, they will transport a great proportion of the detrital matter, held in mechanical suspension by the rivers discharged into them, in the direction of the prevalent movement. Now there are two great movements in the waters of the sea, more particularly felt on coasts and in shallow water; the one

caused by tides, the other by prevalent winds—by the evaporation of an inland sea communicating with the ocean, greater than the supply of water it receives from rivers, which causes a rush of water from the ocean into it—and perhaps also, to a certain modified extent, by the motion of the earth on its axis. Of the latter, commonly termed marine currents, many act in constant or nearly constant directions, while some drive part of the year in one direction, and during the other part in another directly opposed to it. The movements caused by tides for the most part act in directions opposed to each other; so that the same great body of water is moved backwards and forwards, a few hours one way and a few hours the other, local causes producing local variations both as to the relative times of the opposite movements, and in their intensity.

f. The observer should direct his attention to the various local circumstances which may influence the deposits in a delta formed in the sea, more particularly with reference to the disturbing movements above noticed, and to the exposure of the coast to the action of the waves, care being duly taken to estimate the value of the depth of sea into which the delta is protruded. If there be little movement from tides and currents, he would expect to find, under otherwise equal circumstances, that there would be a tendency to form a more muddy deposit on the margins of a delta so situated, than where tidal or other movements were brisk. Due attention should be paid to the influence of wood and small trees borne down a river, since they become entangled where the velocity of the stream is unable to keep them from doing so, and cause obstacles on which

detrital matter accumulates. The exterior of a delta is also greatly modified by the piling action of the waves, when such takes place, as will be noticed in the sequel.

g. Among so many modifying circumstances, it would be difficult to afford the observer very direct information as to any general character of the resulting deposits obtained from detrital matter thus forced into seas. They will necessarily be more complicated in one locality than another; inclined beds may be produced by the friction of the rivers on their channels, which necessarily are disposed to shift, while more horizontal beds result from the quiet deposit of sediment from mechanical suspension in the water. The occurrence of gravel or coarse sand in such deposits will necessarily be rare in proportion to the extension of the delta, since the general velocity of the discharged waters is diminished according to such extension, both from the increased line of level or nearly level channel, and from the frequent checks offered to the onward course of the river, which tend to split the main streams into numerous minor branches.

h. Attempts have been frequently made to calculate the quantity of solid matter borne down by any given river, either into the sea, or in some particular part of its course. When we narrowly examine the manner in which the experiments have been conducted, there are few results which can in any manner be considered as approximating to the truth. When we consider that there are two processes by which detritus may travel onwards in a river, the one pushing, the other transporting by mechanical suspension, both of which frequently co-exist in the same river, it will be obvious

that observations made only on the one cannot give the amount of both. The relative amount of the pushing process can scarcely be estimated except by observing the time required to fill up or occupy any given space, such as the accumulation necessary to fill up a space of given depth, breadth, and height, or the time required to advance any given delta a given distance; the slope of the delta, and the depth of water into which it is protruded, being accurately known.. Much might therefore be done at a delta, if all the matter there collected resulted from the pushing process: but as part of such accumulations is generally due to a deposit from turbid waters checked in various places, we do not obtain satisfactory results. It should be recollected that the same detritus which is held in mechanical suspension in the higher part of a river-course may fall to the bottom, from diminished velocity of the stream, in another and lower part of its course, and be then pushed onwards by friction: and this power may finally cease to act from still further diminished velocity. So that it by no means follows, if the quantity of matter mechanically suspended in a given river, in a part of its course distant from the sea, could be accurately known, that such matter was actually borne into the sea, even when there should not be any intervening lake to arrest its progress.

The usual process of estimating the quantity of earthy matter mechanically suspended in a turbid river, has been to ascertain the figure of its bed at the desired place, and its velocity, which is supposed to give the quantity of water which passed that given spot in a given time. Certain measures of the water are then

obtained, such as a cubic foot, and the quantity of sediment from it ascertained. Sometimes these measures are obtained from one or two, or even three different parts of the river; but more frequently only from one, somewhat centrical. In the first place, the laws by which a river is retarded in its course by friction are not correctly known, without which the exact quantity of water passing down a river cannot be ascertained; and in the second, we do not yet know from whence to take up given measures of the water, so that anything like an approximative mean of the detritus moving forwards in the water can be obtained.* An observer will therefore experience great difficulty in estimating the amount of detritus carried by any given river to the sea, or in given parts of its course. This, however, should not prevent him from doing the best he can with the existing knowledge on such subjects; for if he record the various precautions he may employ to guard against error, his observations may not eventually be thrown away.

i. The modifying influence of tides should be duly attended to in those situations where they flow up deltas to different distances, as is the case with that of the Ganges. The accumulating power of mangrove trees in tropical countries in similar situations should on no account be neglected, since it is frequently very considerable.

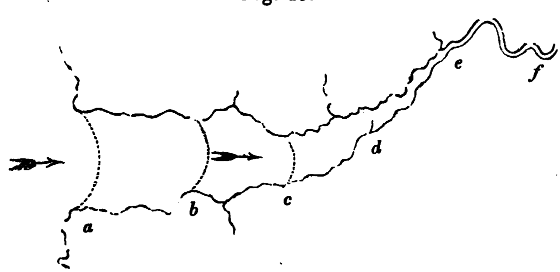
k. It can be scarcely necessary to remind the observer that all rivers do not form deltas where they flow into the sea; and that, on the contrary, some have

* For remarks on this head see "Researches in Theoretical Geology," p. 68.

large wide embouchures into which tides freely flow. Local circumstances necessarily produce a great variety of effects between those observable in the open mouth of the St. Lawrence, and in the deltas of the Indus or the Ganges. The observer will find that the proportionate number of open-mouthed rivers is greatly less on the coasts of tideless or nearly tideless seas, and of great lakes, than on the shores of the ocean; and that where large estuaries exist, the tides are strong, all other things being equal. The amount of detritus pushed forwards by friction must greatly influence the power of a river to form a delta. The quantity of detrital matter borne to the sea must greatly depend upon the kind of country which the rivers traverse; but, all other circumstances being equal, those rivers which can push forward the heaviest and largest detritus would most readily accomplish the formation of a delta.

l. The exposure of a river's mouth to the full force of the tidal wave, if the power of the river and quantity of detritus borne down be not relatively very considerable, greatly tends to keep an estuary open. If the annexed sketch (Fig. 48) represent an estuary open to

Fig. 48.



a tidal wave, then the height of the wave will be greater at *a*, where it strikes the mouth of the estuary, than in the open sea; and it will be still higher at *b*, and run with greater velocity than at *a*; because the same quantity, or nearly the same quantity of water, is driven into a narrower channel. It thus goes on increasing in height and velocity until it loses the propelling power of the water behind it, arising from the ebb of the tide at the mouth of the estuary, and becomes checked in velocity and lowered in height from the want of support behind it; so that the friction on the sides and bottom of the channel, which always retarded the waters to a certain extent, the rise of the channel itself, and the force of the pent-back river-waters, come forcibly into action, and the tidal wave proceeds no farther. We may, for the purpose of illustration, suppose that the tidal wave increases in velocity and height in the estuary represented above (Fig. 48) from *a* to *d*,—*b* and *c* being intermediate stages,—and that from *d* it decreases by *e* to *f*, where it is finally stopped.

The observer will at once perceive that the transporting power of a body of water so circumstanced will vary considerably in different places. The turbid waters of the river, of which the estuary forms the embouchure, are necessarily discharged into this mass of tidal waters, sometimes swept outwards, sometimes inwards, according to the ebb or flow of the tide. So long as the agitation of the estuary water is sufficient to keep it mechanically suspended, the fine detritus cannot be deposited except in those situations where diminished agitation will permit it to fall down. It can, however, only permanently be brought to rest in such

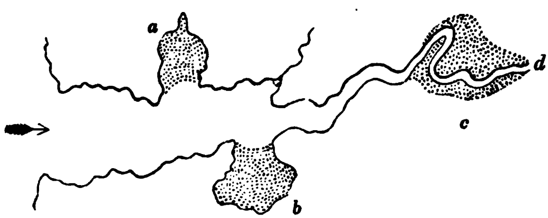
situations on the shores as are not exposed to the disturbing power of the breakers; and thus, unless the annual amount of accumulated mud or silt be greater than the annual amount carried off by the action of the breakers in such places, there will be no permanent increase. Hence, notwithstanding the general muddy character of the shores of estuaries, no permanent increase takes place, except under the above circumstances, or when the breakers pile up beaches on low shores, and thus render tracts of country behind secure from their ravages; so that such tracts would be filled up by sediment, if small channels of communication were open, as frequently happens, to the height of the estuary waters.

m. The power of the river to push detritus forward necessarily receives a check proportionate to the force of the flood-tides, which may even force back such detritus by friction. As the tides vary in power, and the like happens to the river, according to the quantity of water in it, there will be a space where gravel or sand, as the case may be, is accumulated: these are frequently known by the name of *bars*, and their situation depends on a great variety of local circumstances, which an observer will take into account when he has any particular estuary or river under examination.

Much detrital matter will, however, under all circumstances be committed to the body of estuary waters. Now, although the strength of tides in such situations is sufficient to keep a great quantity of it mechanically suspended, so as to render the estuary waters highly turbid, it is clear that if a deposit did not take place somewhere, such waters would eventually acquire so

much fine detritus as to be mere mud. The observer will find that the heads of estuaries have a tendency to fill up, as also the sheltered places ; but that, generally speaking, the deposits at the heads are more gravelly and sandy than those of merely sheltered places, into which gravel and sand are not driven by a tributary stream. To illustrate this, let the annexed sketch

Fig. 49.



(Fig. 49) represent an estuary ; then it will generally be found that the deposit at the head, *c*, is more gravelly or sandy, particularly in its lowest parts, than in the merely sheltered positions, *a* and *b*. And this arises because the detrital matter pushed forwards by the river, *d*, has been arrested at *c*, while in the sheltered spots, *a* and *b*, the sediment has been deposited from the turbid waters checked in their movement, and rendered more or less still according to circumstances.

Notwithstanding the deposition in the sheltered places on the sides of estuaries, and at their heads, a time must come, supposing a large amount of detritus to be brought down during a series of ages, when the sheltered spots will be filled up, and an increase take place only at the head. The quantity of fine detritus

required to fill up the sheltered places, even supposing the increase at the head to be a constant quantity, will go somewhere, and would render the estuary waters gradually more turbid unless deposited. Now the deposit may either take place in the channel of the estuary itself, or be carried into the sea, to be there distributed. The first supposes that the velocity of the tides is insufficient to cut it up when deposited, or prevent its being deposited at all; and the second, that it can escape into the sea.

Some estuaries are so long,—such, for example, as that composed of the Bristol Channel, and its continuation up the tidal waters of the Severn,—that the *surface*-waters at their mouths, if we may use the expression, are not turbid at any time of tide, while the whole of the turbid waters are apparently driven backwards and forwards by the tides in the more inland parts. To enable turbid waters to escape seaward under such circumstances, they must necessarily have a movement in such directions. Now the mere movement of the waters in a long estuary could not produce this effect if the line of turbid water did not come, at the lowest state of the ebb-tide, outside the estuary altogether, when probably, from the general movement of the tide on the open sea-coast, a portion of such turbid water would not again be forced into the estuary, as may be well observed in short estuaries, or those where the line of turbid waters always extends into the sea at low ebb.

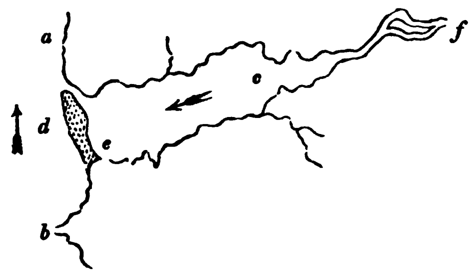
We have, however, to consider that the water of an ebb-tide in an estuary has all the waters of the rivers and streams, pent back by the flood-tide, added to it. Upon their relative weights or specific gravities would

depend the power of the pent-back river-waters to float upon or sink beneath the sea-waters forced into the estuary; which themselves, or at least such portions of them as are washed backwards and forwards by the tides, become brackish and increase in freshness as they approach, and become agitated with, the rivers and streams. There is, therefore, complicated action; and the inquiry ends with the power of the detritus to escape from the long estuaries seaward beneath the clearer waters above, either by the friction on the bottom of the surplus accumulated waters flowing seaward, so that the general sea-level be maintained, or from the same waters being rendered heavier by the amount of detritus mechanically suspended in them, so that they keep the bottom and remain unseen. It will be obvious that the observer may in a great measure discover how far this may be the case, by taking water from different depths in different parts of a long estuary at marked and various times of tide, and by examining their relative specific gravities and the quantities of detritus they may contain.

n. We have not space to enumerate the various modifications an estuary may sustain. It will be sufficient to notice those cases in which, at the meeting of estuary waters with the main sea, the power of the tides is unable to prevent a deposit of detrital matter where the ebb-tide of the estuary is checked by its entrance into a sea, the tidal movement of which is not prolonged in the direction of the estuary ebb, but takes a course frequently at right angles to it. When such a deposit takes place, the accumulation across the mouth of the estuary, usually termed a *bar*, is greatly assisted,

and eventually greatly modified, by the piling action of the breakers falling on the coast generally. Let the annexed sketch (Fig. 50) represent a line of sea-coast,

Fig. 50.



a b, from which an estuary, *c*, runs nearly at right angles into the land, and terminates in the river, *f*, that discharges a considerable quantity of detritus into it, particularly during freshes or floods. Let us further suppose that the ebb-tide has commenced in the estuary, as it usually does, after the ebb has acquired considerable strength along the line of coast, *a b*, and that the latter runs in the direction of the arrow, *d*; then the turbid estuary waters, descending in the direction of the arrow in the estuary, would meet the general movement of the sea on the coast nearly at right angles, and they would consequently receive a check where they attained the line of coast, and a deposit, *e*, would be gradually effected in such situation, which would be greatly modified and assisted by the piling action of the waves falling on the general line of coast, *a b*, as will be noticed under the proper head. There are few rivers which have not, from these causes, bars at their embou-

chures: they are greatly modified according to local circumstances, to which the observer must direct his attention. In some rivers the bar is so considerable as greatly to obstruct the navigation into them, and even, in extreme cases, may be said to close up rivers which would otherwise possess great commercial advantages. In the case above supposed, the estuary is necessarily short, or one where a large proportion of the turbid waters escapes into the sea at every ebb-tide. The observer should note the kind of deposits which, from the check of the bar, take place in the estuary, as also the kind of bottom in the sea immediately outside, or seaward, which he will generally find most clayey and muddy in the direction of the ebb-tide along the coast, because the turbid waters, from obvious causes, there part with the greatest part of the detritus they may contain.

o. As the observer cannot directly view the manner in which detritus is now deposited at the bottom of the sea, he can only approximate towards such knowledge by directing his attention to those circumstances which must influence products of this description. From the operation of geological causes, beds of clay, sands, and the like, are indeed brought to light, and are inferred to have been formed beneath the sea, because they abound with the remains of marine creatures, even of those found in the seas of the present day, and therefore certainly known to be such; and thus opportunities are afforded for studying the effects produced. This will not, it is obvious, afford an observer the necessary data for judging of the extent to which given marine deposits can take place, of the mode in which

they are accumulated, or of the subordinate causes which may greatly influence them. Above all, it will not teach him the extent to which the forces daily in action on the surface of the globe can account for those masses of detrital rocks, of different geological ages, which occur in various parts of it.

p. By sounding in the usual manner with the lead, we have direct evidence that the bottom of the sea consists of mud, silt, sands, gravel, marine shells both broken and entire, portions of corals, and the like. Now, as from geological facts we possess evidence that the relative positions of dry land and sea have not been constant, but that, on the contrary, a large proportion of the present dry land once constituted the bottom of the sea, while dry land must frequently have been submerged beneath the latter, these events having often occurred in the same parts of the earth's surface, we cannot be certain that the mud, sands, and gravel found beneath the present seas were deposited there from such seas during the existing relative positions of sea and land, in any particular area under consideration. It may be highly probable that the mud, silt, and the like, found beneath the seas which bound any particular tract of dry land, may have been carried to their present positions by those movements in the seas that are now observable in the same situation; but to feel assured that we do not fall into unperceived errors on such a subject, we must first take all the circumstances of such sea-movements into consideration, carefully weigh the whole of the evidence, and then see how far such movements could carry the observed mud, silt, sands, or gravel, as the case may be, to the localities

where they are now detected. Such observations, no doubt, require considerable care; but their geological importance is so great, that those who possess good opportunities, as often happens to naval men, should on no account neglect them. It is to the want of sufficient data on this head that we may attribute those loose generalizations so often hazarded in geological treatises and memoirs, and which, when closely examined, seem to rest on little else than the good-will and pleasure of their authors.

q. From various causes, previously noticed, detritus derived from dry land is committed to the sea. It is necessarily distributed over greater distances by the movements produced by tides and currents, than it would be if the waters of the sea were perfectly stationary. The tidal wave is only a great undulation causing little appreciable horizontal movement, except on coasts and in shallow waters, where, viewed generally and by itself, it produces a backwards and forwards horizontal motion of the same waters for a distance of about sixteen to twenty miles; local causes sometimes extending this distance, at others diminishing it. Marine currents act more extensively, and traverse the ocean in different directions; though it may be stated that a larger mass of sea-water is moved from East to West in the Equatorial regions than in any other direction in any other part of the globe. The depth to which such currents extend, when their surface velocity is known, has not been ascertained; though if we take surface causes for their origin, such as prevalent winds, the rush of water from the ocean into an inland sea, to restore the loss from evaporation, and the like, we

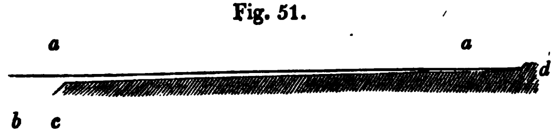
cannot anticipate that they will be very deep. This is a subject to which the attention of the observer is strongly invited: the only direct experiment made, that we are aware of, is that recorded by Captain Becher, who found in lat. 15° 27′ 9″ N., and in long. 17° 31′ 50″ W., that a current moving at the rate of 0·75 per hour had the same velocity at the depth of forty fathoms as on the surface.

r. When an observer is desirous of estimating the direction and extent to which detritus, derived from any particular line of coast, is drifted by movements in the sea, he should, after duly noticing the quantity and kind delivered into the sea on such line of coast, proceed to examine the direction and extent to which tidal movements may bear it, taking into account any probability of a movement sufficiently strong to shove the sands and silt forward on the bottom. In fact, he should endeavour to ascertain if the pushing process caused by the friction of the moving water, and the simple transporting action by mechanical suspension, do or do not co-exist in the streams of tide; because, if they do, the resulting deposit would necessarily be more complicated than if one only were in force. If a stream of tide were sufficiently strong, it would push detritus before it when no appreciable quantity of detrital matter was disseminated through its waters; while, on the other hand, deposits may be effected from gently moving waters, more or less charged with such matter, which are unable to move forwards the mud, silt, and sands on the bottom. As in the case of rivers, we do not correctly know the laws which regulate the retardation of moving sea-waters by friction on the bottom

over which they pass, and therefore are unable to calculate the value of such friction, when the depth of water and surface velocity are known. Hence direct experiments to clear up this subject are particularly desirable. The observer should bear in mind, that sea-water being heavier than fresh water, there will necessarily be a difference in the amount of retardation by friction, and consequently of friction itself, between the two, even when all other things are equal.

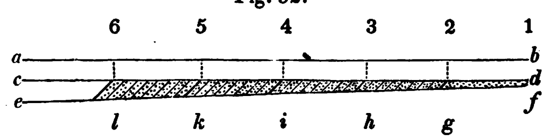
s. Facts connected with soundings, as they are termed, or those depths which are attained by a line of one hundred or one hundred and fifty fathoms in length, would seem to point to a certain pushing power of the tidal movements round coasts, probably combined with that action of waves which, as it were, shake up the finer sediment from the bottom in minor depths, and thus throw more detritus into the power of tidal movements than they would otherwise possess. In many instances also, marine currents, arising from other causes, may assist in producing the effects about to be noticed. It is generally found that the seaward edge of those tracts of bottom, commonly known by the name of soundings, shelve suddenly outwards; that is, after sloping very gradually from the coast to the above-mentioned depths, they plunge at a far more considerable angle seaward. Let the line *a a*, in the accompanying and greatly exaggerated section (Fig. 51), represent

Fig. 51.



the surface of the sea, and the inclined line beneath it that of soundings extending from the coast, *d*, to the deep sea, *b*. Then it will be generally found that, after continuing gradually to deepen, the soundings will more suddenly plunge at *c*, where we suppose a depth of about one hundred fathoms, into deep water. In these cases, which are well shown on the outer verge of soundings connecting France with Norway, and including the British Islands, where the line of two hundred fathoms is but a short distance outside that of one hundred fathoms,* there is much to remind us of the form in which detritus is arranged in some deltas, if we make a section along their length. The supposition that tidal movements can produce this form at considerable distances from the land may, at first sight, appear inconsistent with the relatively small backwards and forwards motion noticed above. This difficulty seems, however, more apparent than real. Let *a b*, in the annexed section (Fig. 52), represent the surface of a por-

Fig. 52.



tion of sea exposed to tidal movement, so that the point 1 moves to the point 2, 2 to 3, 3 to 4, and so on, during the ebb tides, and the respective points move back to their respective places during the flood; so that, in fact, there is a to and fro-movement of the whole, to the

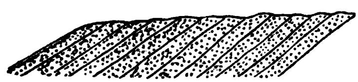
* See the chart and remarks in "Researches in Theoretical Geology," p. 190.

amount of the distance from 1 to 2, 2 to 3, &c. There would be modifying circumstances, to be noticed hereafter; but, for greater simplicity, we will now neglect them. Let the line *c d* be the depth to which the tidal movement has the power to shove superficial and given kinds of sand, silt, mud, or the like, backwards and forwards; and let *e f* represent a bottom of solid rock sloping from the land to the depths of the ocean. If we now suppose detrital matter deposited and to a certain extent levelled from *f* to *g*, any additional quantity would be thrown over at *g*, by the to and fro movement of the portion of water, comprised between 1 and 2, to the space 2, 3, which in its turn moves in a similar manner to the space 3, 4; and so on. The given detrital matter brought over the steep slope *g* could not be again moved back to *f*; for it would not only be beneath the line of shoving power *c d*, but it would also require a power sufficient to push it up the steep slope *g*,—one which, under the circumstances enumerated, could not exist. Hence, if detrital matter, capable of being pushed about by the tidal movement, at the depth *c d*, be constantly added on the side *d f* (that of the land), the same forces will continue to level the upper part to a certain extent, accumulations of shelving beds being added to the seaward steep slope, which will go on advancing in the direction *h*, *i*, *k*, *l*, and be more slow in such advance in proportion to the increased depth of the water.

This explanation is merely thrown out as a hint to the observer, who has to consider that the movements of a stream of tide are greater in proportion to the proximity of land, from the resistance opposed to the tidal

wave under such circumstances, and therefore that the distances, 1, 2, 3, 4, 5, 6, would not be equal, but decrease seawards, or from 1 to 6; as also that the line of soundings is not horizontal, but inclined at a very small angle; and that the whole deposit may be greatly modified by the accumulation of fragments of shells, corals, fish-bones, &c. over fine detrital matter; thus preserving it from that movement which could just disturb it. Many other modifying circumstances will also strike him, if he direct his attention to this subject, which has been more especially introduced to see how far a series of somewhat highly inclined shelving beds of sand or silt, such as are represented in the annexed section (Fig. 53),

Fig. 53.



may in this way be produced; and, consequently, how far the accumulation of soundings, supposed to be in progress in the present day, may account for sandstone and schistose beds so arranged, that, if we are to suppose them to have been deposited horizontally above each other at the bottom of the sea, we must also suppose water of far greater depth than, in all probability, now exists in any part of the ocean, or which we should conceive ever has existed.

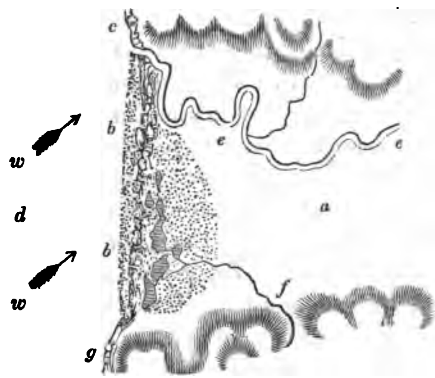
t. Deposits from marine currents, in which detrital matter is disseminated, would necessarily be more extensive than those from tidal streams, if detritus were discharged into them to an equal extent, since they flow over far greater surfaces. We might hazard some conjecture as to the distance to which mud or silt would travel

by such means, if experiments were made on the time it took for fine disseminated detritus of different kinds to settle at the bottom of *sea-water* a yard or any other convenient measure in depth, and also knew the depth to which a given current, moving with an ascertained velocity, extended; but, unfortunately, respecting all these essential data we are as yet uninformed. While on this subject, it may not be without interest to consider how far the increased density of water, in the lower parts of the deep ocean, from superincumbent pressure, would retard the fall of the finest detritus, supposing such to be brought to, and deposited from, marine currents in such situations. To ascertain how far detrital matter may be contained in marine currents, in various parts of their course and at various depths, not only the proper instruments for taking water up from the required situations are necessary, but also such opportunities as the naval man can almost exclusively possess, and these not unfrequently. Water which may be thus procured should be carefully bottled, and sufficient quantities should be obtained to detect the small amount of detritus which probably will alone be found in it.

VII. *Accumulation of detritus on coasts by means of breakers.*—*a.* On those parts of coasts which are nearly on a level with the sea when tideless, or which rise little, if at all, above high-water in tidal seas, the observer will find that there is a tendency to force shingles and sands on shore, long lines of shingle-beaches or sandy dunes being accumulated in front of level tracts of country so situated. Such beaches or sandy dunes not only protect lowlands from the inroads of the sea, but frequently modify the lowlands themselves, either

by preventing the minor drainage of the country, which thus readily forms into marshes, or are the cause, if composed of sand, of great inroads of such sand, which is blown over the neighbouring districts; whole bodies of it even advancing at a slow but certain rate, as is well seen in the line of sandy dunes extending from the mouth of the Garonne to the district of Bayonne. Let the annexed sketch (Fig. 54) represent a tract of low

Fig. 54.



level land, *a*, bounded seaward by a shingle or sandy beach, *b b*, which protects it from the ravages of the sea, *d*; and let *e e* be a river which delivers itself into the sea between the cliff *c* and the beach *b*, while *f* is a minor stream unable to pierce through the beach *b b*, and therefore loses itself in pools and marshes behind it, partly percolating through the beach, and partly soaking and rendering the ground marshy towards the river *e e*.

The observer, if placed in such a situation, which we

have supposed, for more easy illustration, to be comprised within a somewhat limited area, should endeavour to discover the manner in which the beach itself is produced. As beaches travel in the direction of the prevalent winds, he should ascertain the kind of pebbles, if it be a shingle-beach, composing the one before him If he find them such that they are evidently rounded fragments of rocks derived from the cliff *g*, and others in the same direction, he will conclude that they have been brought from thence by the small oblique action given to waves by prevalent winds striking the coast in a similar direction. In the sketch before us (Fig. 54), these winds might strike the line of coast in the direction of the arrows, *w*, *w*. If this were the case, the drift would continue towards the cliff, *c*, and would only be prevented from reaching it by the force of the river, *e e*, which is supposed strong enough to drive the accumulating pebbles outwards. It will be obvious, if this were the state of things in the above situation, that the area, *a*, may not only have been exposed to many changes during the production of the beach, *b b*, but may still continue to be so. As all areas so circumstanced vary according to local conditions, the observer should direct his attention to such conditions, carefully estimating which may have most influenced the present conditions of the particular area examined.

The chief geological value of observations of this kind is to see how far they may be found to illustrate those alternations of marine, estuary, and fresh-water deposits, often found, particularly among the supracretaceous or tertiary rocks. The observer should endeavour to obtain sections of such flat lands, which may

often be seen in deep drainage cuts; and he should collect organic remains, if he can, (in the manner noticed in the sequel,) from any beds of gravel, clay, or sand which may be thus exposed.

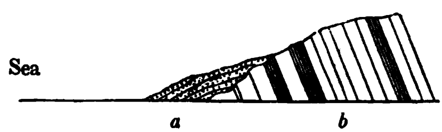
With regard to the deposit of detrital matter in such situations, much would depend upon the power of the river, *e e*, to keep a passage open into the sea: if a heavy gale of wind, acting on shore, force up a bank against it, the river would overflow the lowlands; and if charged with detrital matter, some part of it might be deposited on them. The minor stream, *f*, would constantly add detrital matter brought down by it to those places where it loses both its pushing power and transporting velocity, and might be the cause of a great mixture of vegetable substances, grown in the ponds and marshes, with sands, silt, and mud.

b. When sands are blown from sandy dunes inland, as commonly happens, the observer should endeavour to ascertain the amount of land thus covered, (and it is often considerable,) the rate of advance, and the general thickness and character of the resulting deposit; noting alternations of vegetable matter that mark the various surfaces which, for a time, were sufficiently stable for the growth of plants, and which became respectively covered by the sand-drift.

c. Sand-drifts are not always confined to those low tracts of land between which and the sea there are dunes affording the necessary dry sand. Sand-drifts sometimes take place at the bottom of deep bays, exposed to heavy waves rolling over shallow sandy depths before they reach the coast. The observer will find several examples of this fact on the coasts of Cornwall and

Devon. The sands in such cases are very frequently little else than comminuted sea-shells. The resulting deposits are geologically interesting, particularly as land-shells and the bones of land-animals are often overwhelmed by new drifts. The sections also are interesting, being sometimes such as above (Fig. 55); *a* being the drift-sand, and *b* the rock of the hill against which it is drifted.

Fig. 55.



VIII. *Chemical deposits from fresh and sea-waters.* —As waters from springs are not pure, but contain various substances in solution, and as these are the chief sources whence rivers are supplied under ordinary circumstances, it follows that in large rivers into which many tributaries deliver themselves, and in lakes, there may be numerous substances in solution, which, when mingled together, may have a tendency to act upon each other, and produce new and insoluble compounds.

a. When an observer suspects that calcareous or other substances are thrown down from waters in which they were previously held in solution by the necessary quantity of carbonic acid or other substances, as the case may be, he should carefully obtain water from the rivers or lakes under his examination, and see if such substances are really present in their waters. If he be unable to analyze it himself, he should put the water into a clean bottle, immediately seal it up carefully and

tight, and forward it to some experienced chemist for examination.

b. It would be highly desirable to ascertain the approximative amount, as well as kind of substances, held in solution by the waters entering different lakes, and then obtain those of the waters at the discharging outlets, in order to estimate the kind and amount of chemical deposits, if any, which may take place in such lakes. If these latter be shallow and extensive, evaporation alone might cause appreciable effects, particularly in warm latitudes. If calcareous matter be considered to be left in the waters of the lake, due regard should be paid to its probable consumption by the shelled molluscs inhabiting it, and also to the accumulations that may thence arise.

c. Observers would gradually accumulate a large amount of valuable information on this subject, if, when unable to analyze waters themselves, they collected with the necessary care, for examination by proper persons, those of various rivers which discharge themselves into the sea. If this were done for any particular line of coast, not neglecting the minor streams, which, collectively, are as important as the larger rivers, we might obtain an approximative knowledge of the general amount of the substances, as also of their relative kinds and proportions, thus transferred annually from the dry land so drained into the sea. It would be highly interesting to know, if it be only approximatively, the amount and kind of matter thus thrown in a state of solution into the seas which surround the British Islands.

d. It may be very true that various rocks, supposed

to have been formed chemically beneath the waters of the sea, may have been really so produced; but it remains to be seen whether we must not employ the term *sea* in a more enlarged sense than is usually done by geologists. At present it seems to be supposed that the saline contents of the sea have always been such as are now discovered in the waters of the ocean. This may be true also, though there are reasons which may lead us to a contrary opinion; but neglecting these for the present, it may be observed as a curious fact, that hitherto no direct experiments have been made to discover under what conditions calcareous or other deposits, resembling those of known rocks, can be produced in *sea-water*. The line of research will readily present itself to those possessed of competent chemical knowledge; and it would be highly important to ascertain the extent to which the present saline contents of the ocean would carry us in accounting for those large masses of calcareous matter, which we consider to have been of marine origin, because in them we find the remains of shells analogous to genera, and sometimes to species, which now exist in the sea. The presence of such exuviæ by no means proves that the seas inhabited by the creatures of which they constitute the remains, were precisely the same, as respects saline contents, as those of the present ocean; since we know that such creatures can be brought to live in a medium which may vary considerably in this respect. Moreover, the waters of the Mediterranean are more saline than those of the Atlantic; and yet several species of molluscs are common to both. It would seem that waters may be ex-

ceedingly saline, and even contain a different proportion of certain salts, as is the case with the Caspian, and yet molluscs thrive in them.

e. As siliceous deposits take place from some thermal springs, search should be made in the vicinity of such springs, particularly when very hot, for the purpose of observing how the rocks to which siliciferous waters may have access, may be influenced by them; the mode in which sand may be agglutinated by these means; as also the time required to cover vegetables with a sufficient coat of silica to arrest decomposition. Experiments to ascertain the latter point would be highly interesting; since there exist siliceous fossil vegetables, which would seem to show that plants may be so speedily covered and impregnated with silica as to stop that decay which might take place in a few days, particularly in tropical countries.

f. The angles at which successive coatings or beds of substances, analogous to those of rocks, have been deposited either from natural or artificial solutions, should receive attention; since they may afford us information as to those we may allow for original deposition, and for disturbance after deposition, when the dislocations and fractures of any particular country are under examination.

IX. *Manner in which organic remains may be entombed in rocks now forming.*—If the distribution of animal and vegetable life over the face of the globe be important to the study of organic remains generally, the mode in which the exuviæ of such animal and vegetable life may be now entombed is not less so.

a. There can be scarcely any one who has seen sec-

tions of ground laid open for roads, ditches, or other purposes, who has not observed that the shells of the common snail and other land-molluscs are often found immediately beneath vegetation, while the bones of reptiles, birds, or quadrupeds are exceedingly rare in the same situations. The rapacious and scavenger animals in general either devour the bones with the other parts of the creatures they destroy, or eat up the bones of dead animals which others have left, and which rarely escape the constant search made by numerous creatures for such offal; consequently few bones remain on the surface of land to be covered by the soil resulting from animal and vegetable decomposition, or from earth drifted by different causes over them. The chances therefore are against the preservation of the bones of animals immediately beneath terrestrial vegetation from ordinary natural causes. With the solid parts of land-molluscs, such as the common snail and others, the case would be different, for many of these molluscs bury and conceal themselves in holes in the ground; and as multitudes die in such situations, and their fleshy parts are there consumed by various small creatures which do not attack the shells themselves, these latter remain to be covered up by earth washed by rains into the holes, and eventually are for the most part preserved entire, or nearly so, in the common superficial soil of dry land.

b. To estimate the manner in which the bones of terrestrial animals may be entombed on dry land under circumstances which may so far be considered ordinary that the necessary conditions exist in numerous parts of the earth's surface, the observer should direct his

attention to the accumulations of fallen fragments of rock and other substances, which take place at the bottom of open cracks and rents in rocks, at the base of precipices, and in caverns tenanted by different creatures, such as hyenas, bears, &c. Into the open fissures so common in many limestone districts, animals frequently fall, either in consequence of being chased by others, by unsuccessful attempts to leap over the fissures, or in consequence of the earth giving way on the edges by their weight. In alpine or cold countries, bridges of snow, stretched over fissures, frequently give way under animals attempting to cross them, and thus the latter are precipitated into the clefts beneath. Into these fissures fragments of rocks, earth, and sometimes plants, also fall from ordinary causes, and eventually entomb the remains of the animals, which may consist of their bones, as entire as they were after the fall; the fleshy parts of the creatures having been decomposed, or devoured by such birds as could descend into the fissure, and were unable to swallow or carry away the larger bones. If the fissure be in a calcareous rock, and there be a stalagmitical deposit of carbonate of lime, as not unfrequently happens in such situations, there may eventually be a compact mass of fragments of rock, bones, and calcareous cementing matter, filling part of the fissure. The observer, when he has any part of a fissure apparently so filled before him, should be careful to remove the bones with great care, in order that, if not conversant with comparative osteology himself, they may be sent to an experienced comparative anatomist in as perfect a state as possible, to decide how far they may be the bones of animals which still

exist, or be those of species no longer discovered living on the surface of the earth, and consequently the contents of the fissure be either referred to the present geological epoch, or to one anterior to it.

When an observer has a fissure filled in the manner above noticed before him, he should not content himself by abstracting bones only from the upper, or merely from the lower part; for it may have so happened that the fissure has continued open during a time in which there has been a change in the animals inhabiting the country; and, consequently, if the same causes had continued to operate, the remains of the earlier tenants of the district would be entombed in the lower part of the fissure, and of the later in the higher portions. Whenever opportunities offer, the observer should note the manner in which bones occur in the retreats of animals which carry their prey into such places in order to devour them;—the broken or other condition of such bones; and the accumulation of earth, animal fæces, fragments of rock, &c. which may cover them.

c. Large tracts of marsh-land, interspersed with small shallow lakes of water, would appear to be situations highly favourable to the accumulation of vegetable exuviæ. The leaves of trees which grow in such situations, falling on the various patches of water, take a horizontal position, forming a layer over the top of them. The leaves gradually soak up water, and are readily pressed down by the accumulation of other layers of leaves upon them, or sink from their own increased specific gravity to the mud at the bottom. An observer should attend to the mode in which the remains of vegetation are thus entombed, particularly in

tropical countries, where such accumulations sometimes take place on a large scale. He should also note the manner in which the exuviæ of aquatic creatures, frequent in such situations, become mingled with the remains of plants, as may also be the case with the bones of many terrestrial quadrupeds. He should by no means neglect to remark the manner in which the remains of animals and vegetables may be preserved in peat-bogs. These are often of considerable extent, and the facts connected with them highly interesting.

d. The fall of great quantities of ashes and cinders, discharged in some great volcanic eruption, would appear to be the cause of a greater sudden entombment of terrestrial animals and plants, with the probability of preserving their more solid parts entire, than can be obtained without the aid of moving water under other circumstances. The dust is sometimes so fine, that with the aid of moisture, which subsequently consolidates it, moulds of the internal forms of creatures may, under very favourable circumstances, be preserved, after decomposition has removed the flesh over which the dust and cinders first fell. Of this fact one or two remarkable instances have been observed at Pompeii, where moulds have been thus obtained of parts of the human form. Such cases must of necessity be exceedingly rare; but the preservation of the osseous remains of reptiles, insects, birds, and quadrupeds, would, we should conceive, be by no means so, particularly in the vicinity of the volcanic vent whence the ashes and cinders were discharged. Plants also, we should imagine, would be abundantly entombed under similar circumstances. Observers, therefore, favourably situated,

should not neglect the search of organic remains amid beds of volcanic ashes and cinders. In Pompeii and Herculaneum they have splendid examples of cities overwhelmed by substances discharged from a volcano, in which are not only found the osseous remains of man, but also an immense variety of his works, extending even to manuscripts, that have thus been preserved from the various causes of destruction to which they would have been exposed had they not been so enveloped.

e. Although the remains of animals and plants may thus, to a certain extent, be preserved on dry land without the aid of moving water, it is to deposits produced by this agent, and to others resulting from chemical changes in bodies of water, that we must turn for the preservation of the great proportion of organic exuviæ now entombed in mineral matter. The observer, therefore, should carefully direct his attention to the diversified manner in which this may be accomplished; so that when he studies the mode in which the organic remains of former geological periods occur, he may be enabled to judge of any difference or resemblance he may discover between them.

When treating of mechanical and chemical deposits effected in lakes and seas, or resulting from temporary floods over land commonly dry, we abstained from noticing that the greater part of such products contain the remains of animals and plants which have, from various causes, been enveloped by them. The fish, molluscs, and other inhabitants of a river, are, under ordinary circumstances, so adjusted to its velocity, volume of water, kind of bottom, and the like, that we can look to little

else than their natural death, which probably is rare, for the preservation of their remains in the mud, silt, sand, or gravel which may happen to accumulate in any particular part of such river. The solid parts of fluviatile molluscs are, perhaps, the only remains of creatures, constantly living in the river itself, likely to be enveloped by detritus thrown down in any part of its course. As, however, numerous rivers cut away their banks, when the latter are not protected by human ingenuity, the observer should direct his attention to the relative amount and kind of animal and vegetable remains that may be thus derived, and subsequently deposited in accumulations of mud, sand, or gravel formed by the river. He should not neglect the power of large trees washed out of the river-banks—as often happens in districts in their natural condition, unmodified by man—to alter the course of the river itself, particularly in level countries; and thus cause accumulations of detrital matter, mingled with organic remains, in such particular situations.

f. The fish in rivers, during floods, being exposed to a greater volume of water moving with increased velocity, seek shelter in situations where diminished velocity, caused by the friction of the water on the bottom and sides, enables them to retain their places. Fluviatile molluscs generally inhabit localities that are secure from the ravages of common floods; but when extraordinary floods sweep down the channel of a river, and leave accumulations of detritus in different situations, an observer would do well to examine such accumulations, and note the manner in which the shells of fluviatile molluscs may be enveloped by the detritus.

During river-floods which may be considered of extraordinary magnitude, numerous terrestrial animals and plants are borne onwards, and are not unfrequently left in those situations where the waters spread over flats and low grounds. An observer should endeavour to ascertain, when the waters have subsided, how far any animal and vegetable remains thus, as it were, cast on one side may become enveloped by sedimentary matter, and how far they would remain exposed to the ordinary chances of decomposition, from atmospherical causes, when uncovered by such matter.

g. The relative amount of organic exuviæ which may be entombed in mud, silt, sand, or gravel, by rivers in their courses, either under ordinary or extraordinary circumstances, is perhaps not great; though, from the change in the river-courses of some countries, more may be eventually accomplished in this manner than may at first sight appear probable. With respect to accumulations of organic remains among the detritus deposited at their embouchures, either in lakes or seas, the case is different.

The greater part of those sedimentary deposits which have been previously noticed as taking place in such situations, not only contain the remains of fluviatile and terrestrial creatures washed down the rivers and brought to rest, according to their relative specific gravities and other circumstances, but also the exuviæ of various creatures which live in the higher parts of the sedimentary deposits themselves, and which are either lacustrine, estuary, or marine, as the case may be. Under ordinary circumstances, many molluscs die naturally, and leave their solid parts entombed at various depths,

according to their respective habits, in the higher parts, for the time, of the accumulated detritus; or are killed by hunting-molluscs, which, after piercing their shells and sucking their juices, leave the solid parts or shells of their prey in the mud or sand, which eventually become still more deeply entombed by the subsequent accumulation of additional detritus.

The observer should attend to the various modes in which the remains of animals may thus be buried in mineral matter, carefully weighing those circumstances which may produce mixtures or alternations of terrestrial, fluviatile, estuary, and marine remains by the mere transport of organic and inorganic matter into given situations. He should recollect that the dead bodies of creatures borne downwards by rivers into lakes or seas may possess different specific gravities, and therefore would be brought to rest according to their state of decomposition at the time, and various other obvious circumstances; that mere bones and shells, unless the latter be so washed away from dry places that they float, would sooner be deposited, under the necessary conditions, than dead animals with their flesh upon them;—that plants or portions of trees would float or sink at unequal depths, according to their relative specific gravities at the time; and that they may be drifted greater or less distances, according to circumstances. In the case of succulent plants, ferns, leaves of trees, and the like, he should mark the length of time and the conditions during or under which they can remain longest uninjured, and the mode in which they may be entangled on the skirts of a delta, the banks of an estuary, and other situations; noting

the different amount of succulent plants, ferns, leaves of trees, and the like, which may be accumulated among the roots of mangrove-trees in the tropics, or by other means in the colder regions of the globe. The observer should carefully estimate, from the facts he discovers, the various probable mixtures of organic substances with detrital matter in any delta or river embouchure he may study, weighing well the influence of any particular condition or conditions which may appear to modify the general product.

Sections occasionally present themselves in deltas when the waters are low, or when portions are raised by earthquakes. These should be carefully examined; and the mode in which organic exuviæ occur, if such are discovered, should be noted. An observer should endeavour to trace whether any organic substances he may discover in such situations have been quietly covered up, pushed forward by the river-waters, or brought to rest in a more sudden and violent manner; which last state is generally marked by a very irregular mixture of all the substances of which the particular deposit is composed.

Extraordinary causes, or floods, can scarcely do otherwise than produce a different kind of accumulation, at the entrances of rivers into lakes or seas, both of organic and inorganic substances, than ordinary causes. When, therefore, sections can be obtained under favourable circumstances, an observer should endeavour to ascertain the different effects produced by this difference in causes; recollecting that organic remains would probably occur in a different manner in one case than in the other, not only as regards their position in the detrital

deposit generally, but also with respect to the relative proportions of the various kinds of animals and plants entombed.

h. Organic remains are most probably enveloped by detritus of various kinds at the bottoms of lakes and seas under circumstances somewhat different from the preceding. The effects above noticed necessarily occur at the junction of lines of rivers with those of coasts; and if there were no antagonist forces in action, the various coast-accumulations of detritus, and of organic exuviæ mingled with them, would tend to form such constant additions to the superficies of dry land, that the areas of lakes and seas would as constantly diminish. Waves breaking against coasts tend, as has been previously seen, to wear them away under certain conditions, while under others they throw detritus from the sea upon the land. Breakers not only eject sand and pebbles, but also molluscs, fish, corals, and other organic substances, under favourable circumstances, upon coasts, where, accumulation succeeding accumulation, a mass of rejectamenta, varying according to local conditions, may be eventually formed. The observer should note the circumstances under which organic remains may be thus enveloped, carefully weighing the modifications which may be produced by local causes in such accumulations. It will be obvious that the surface of water exposed generally in lakes is not sufficiently extensive to permit that nearly constant supply of breakers which, under otherwise equal conditions, would heap considerable quantities of detritus and organic exuviæ on a sea-coast. Waves are indeed more easily produced, other things being equal, on the sur-

face of fresh-water lakes than on that of the sea by a given force of wind, because the liquid acted on in the one case is specifically lighter than that in the other: but then the waves of lakes, when equal in size, do not fall with the same weight as breakers on sea-coasts. Detritus being, however, thrown on the shores of lakes by breakers under favourable circumstances, an observer should examine any sections he can obtain of such accumulations, in order to mark the extent to which organic remains may be included among them.

i. We should anticipate, that in proportion to increased distance from the coast, accompanied by greater depth of water, and the consequent greater tranquillity which would prevail in the lower parts of a lake, there would be a more extensive and more uniform deposit over such organic exuviæ as may be there collected, than on the immediate coasts; and that these organic remains would commonly consist of the parts of creatures which generally inhabit the lower parts of the lake, mingled with the exuviæ of terrestrial animals that have perished in their attempts to cross from coast to coast, or have been carried far into the lake by river-floods. Probably also water-logged wood and the leaves of plants might be accumulated in the same situations.—As these deposits beneath the waters of lakes cannot be seen while forming, an observer can only approximate towards a knowledge of their mode of accumulation by carefully noting the conditions existing in any lake under examination, not only as regards the discharge of detrital matter into it, but also the envelopement of organic exuviæ by such detrital matter. It will be obvious that the conditions will not be

equal in deep and in shallow lakes: creatures which may merely fringe the shores of the former, may cover the whole bottom of the latter; and waves which would not disturb a deposit at the bottom of the one, would move detritus upon that of the other.

k. The foregoing observations in some measure apply to deposits enveloping organic remains beneath the sea at a distance from the coasts. In this case, also, an observer can only approximate towards a knowledge of the effects produced, by carefully noting those circumstances which may directly or indirectly influence them. Allowances must in like manner be made for shallow and deep seas, and the consequent modifications in the accumulations of detritus and organic remains formed in them. In lakes, whether formed of saline or fresh water, the superficies is not in general sufficiently extensive to come within the influence of any great variety of climate; and therefore the distribution of the fish, molluscs, and other creatures living in them, is not likely to be greatly modified by this cause. With the inhabitants of the sea, the case is altogether different: climate, though by no means the only modifying cause, does considerably influence their distribution.

l. We must refer to the works which treat of the distribution of animal and vegetable life over the surface of the earth for information on that head: it will be enough to state, that multiplied observations on this subject have shown that the same species are not necessarily discovered in any two given localities because the latter are alike as to climate and other conditions; but, on the contrary, if all animals and vegetables now existing on the face of the globe were suddenly to be

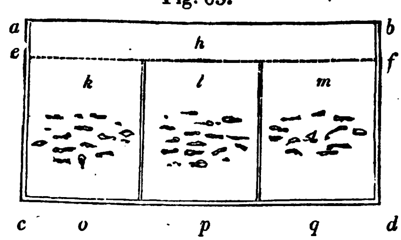
enveloped in a continuous bed of rock, that there would be little resemblance in the organic contents of the various parts at the distance of a few hundred miles from each other: consequently, though contemporaneous deposits of mud, silt, and sand are now taking place, and enveloping organic exuviæ around the British Islands and on the coasts of China, such deposits could not be proved to be contemporaneous by the organic exuviæ contained in each. Neither would any percentage of molluscs found in the deposits, and now existing in their respective neighbouring seas, prove their contemporaneous origin, though to classifications of rocks founded on this circumstance great importance has lately been attached, unless it can also be proved that the shores of the British Islands and those of China have been contemporaneously exposed to exactly the same conditions,—a circumstance that does not appear very probable.

m. An observer can make direct observations on the kind of bottom found beneath the sea, in those depths termed soundings, by means of the common lead employed for such purposes; and on the animal and vegetable life, at small depths beneath the immediate bottom, on the bottom itself, and in the sea, by dredging and fishing. Observations of this kind might be made more instructive than they have hitherto been to the geologist, if charts were constructed, not only exhibiting the depth and kind of bottom on given coasts, but also the force and direction of tides and currents which could transport detritus, the kind of detritus thus transported, and the parts of the submarine area tenanted by particular portions of animal and vegetable

life. By thus speaking, as it were, to the eye, more general and definite ideas are obtained than by pages of description. The scale of such charts would necessarily depend upon the amount of generalization attempted; but we can readily conceive that much general information might be conveyed upon a scale of one inch to the mile, that of the Ordnance Maps of Great Britain.

n. With regard to the mineralization of organic remains in various rocks—that is, the frequent change of the original matter of which the organic substance itself was composed when enveloped in mud, silt, or sand, as the case may be, into that of which it is often composed in rocks—we can readily imagine a series of experiments to be so conducted, though the great element, time, may be wanting, that much information may be obtained on this head. Suppose that an observer is desirous of forming some estimate of the value that should be attached to the percolation of water, charged with carbonic acid, through mud, silt, or sand, upon different organic remains contained in them, we imagine that he can do so by procuring a large vessel or box, of any dimensions or materials that may be considered most convenient, divided upon the principle sketched in the annexed cut (Fig. 56), which is supposed to

Fig. 65.



afford a vertical section of such a vessel or box, *a c d b*. Let this be divided into four compartments, of which three, *o p q*, are equal to each other and open at top, while the fourth, *h*, extends over them horizontally and is open at bottom. Let the compartments *o p q* be now respectively filled with mud, silt, and sand, of chemical compositions considered most convenient for the experiment, up to the line *e f*, and organic exuviæ, such as shells, fish bones, saurian bones, and the like, be placed in the mud at *k*, the silt at *l*, and the sands at *m*, taking care that such exuviæ be as much as possible of the same kinds, and placed in exactly the same relative situations in each compartment. If water charged with carbonic acid be now introduced into the compartment *h*, so as to fill it, it will tend to percolate through the substances in the compartments *o p q*, provided their respective bottoms be constructed of porous materials, as is necessary. In percolating downwards through the respective compartments filled with mud, silt, or sand, the carbonated waters will pass the organic exuviæ, *k l m*, and produce effects upon them according to their respective chemical compositions. If the vessel *h* be constantly supplied with water charged with carbonic acid in proportion as it percolates through the compartments *o p q*, and the experiment be continued a given time, such as a year, the condition of the organic exuviæ in each situation will show the amount of change that has taken place from the percolation of the carbonated waters. Of course the chemical composition of the mud, silt, and sands should be known previous to the experiment, in order that no sources of

error may arise from the action of the carbonated waters upon these substances.

It will be obvious that these experiments may be greatly varied, care being always taken to produce such effects as we may conceive to take place in nature; and that a great diversity of apparatus may be contrived for the purpose. We may even attempt to replace by other substances such parts of organic exuviæ as may be removed by the action of the solutions employed to percolate through mud, silt, or sands. With care we may, perhaps, obtain the complete removal of the carbonate of lime of shells by such means, such as has often been accomplished in natural processes, and succeed in introducing other substances, such as silica, into the resulting cavity. These and other experiments to illustrate natural processes by artificial means belong to what may be termed 'Experimental Geology,'—a branch of the science which has not hitherto received that general attention which its importance demands.

o. The principal mineral substance composing rocks which contain organic remains and are referred to a chemical origin, is limestone. In general, organic exuviæ are well preserved in calcareous deposits, which can be observed to take place in various situations where waters highly impregnated with carbonic acid lose that acid, and the carbonate of lime, previously held in solution by the aid of the carbonic acid, is thrown down upon any substance it may encounter. Organic substances are thus enveloped and preserved in calcareous matter, possessing various degrees of hardness and solidity, according to modifying circumstances. Petrifying springs, as they are termed, are known to every one. The sub-

stances placed beneath them are merely encrusted by the deposition of earthy matter, usually carbonate of lime, either by the loss of the substance from the water which held them in solution, or by the evaporation of the water altogether. An observer will readily perceive that such springs commonly collect together numerous plants, land-shells, bones and stones, which thus become cemented into a constantly increasing mass. He should direct his attention to those situations where ponds or small lakes are formed of carbonated waters, holding carbonate of lime in solution, and observe the mode in which organic remains often become enveloped by a calcareous deposit. The courses of running waters also will be found covered by calcareous deposits under the necessary conditions. When such deposits of calcareous matter, commonly termed Travertin or Travertino, are before him, an observer should endeavour to estimate their geological value, by noting the organic exuviæ they contain, their extent, depth, general character, and relative importance as portions of mineral matter forming a component part of the district.

p. Other substances, such as silica and sulphate of lime, are thrown down from mineral springs, as they are termed, in some situations: the mode in which they envelope animal and vegetable remains, their relative importance, and the conditions under which the resulting deposits are produced, should be carefully noted.

q. It is inferred that limestones are now forming extensively beneath the sea in many situations, and there envelope organic remains. Direct evidence on this subject cannot well be obtained, further than by

seeing if carbonate of lime be thrown down from sea-water, and envelope such exuviæ of animals and plants as it may encounter. Hitherto the evidence on this head has been extremely scanty; but marine shells and corals have been obtained which were cemented by compact calcareous matter, apparently the product of the present geological period; and stones and sand have been stated to have been taken from beneath sea-water, which were agglutinated by carbonate of lime, now forming in the same situations. If the saline contents of the sea be the same now that they were during the time when many calcareous deposits, full of marine shells, &c., were effected beneath the seas of former geological periods, we can see no reason, *à priori*, why similar deposits should not now be in progress. An observer should take into account the various conditions necessary to produce a calcareous deposit beneath the waters of the sea, containing the saline substances they now do, coupling it with the existence of creatures, the more solid remains of which may be subsequently entombed in the same situations.

r. Coral reefs have been considered by some to be extensive; that is, to cover a considerable submarine area with a broad sheet of calcareous matter, formed of the hard parts of saxigenous polypi, cementing shells and other hard parts of marine creatures. Others again consider, that they do not uninterruptedly cover extensive areas, but occur in isolated patches on the summits of submarine mountains, or in lines skirting coasts. No class of observers can possess such opportunities of studying the various conditions under which coral reefs

and banks exist as naval men, or of collecting data as to the depth at which certain species of coral descend in the water, the extent of such reefs, and the like. It would be desirable, if an observer be unable to distinguish the different species of corals himself, to grapple up specimens from different depths on the skirts of a coral reef, carefully put them away in some soft substance, so that the finer portions remain uninjured, with labels as to depth and situation whence they were taken, in order that they may be eventually submitted to the examination of experienced naturalists.

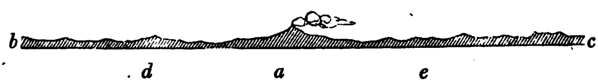
X. *Volcanos.*—From the striking character of volcanic phenomena, there are few persons who, being near a volcano at a time of eruption, have not to a certain extent become observers of such phenomena. In general, however, the observations made are of little value, with the exception of those recorded by a few scientific individuals, from the want of attention to those facts which more particularly deserve notice, and which lead to a right understanding of the cause of volcanic action.

a. An observer should in the first place attend to the situation of the volcano; not confining himself to the mere mountain itself, but taking in as much of the surrounding country as circumstances will permit. If the volcano be situated in a district composed of non-volcanic rocks, great attention should be paid to the position of the beds of such rocks, if they be stratified; noting whether or not they dip away from the volcano as a centre, or take other positions. Above all, it is necessary to sink the importance of the volcano itself, whatever may be its magnitude, in that of the district generally; by no

means allowing the splendour of the eruptions, and the personal danger frequently attending observations at such times, to interfere with a correct estimate of its relative size as a part of the earth's surface.

There is no better mode of reducing the undue importance an observer may attach to a single volcano, than by constructing a strictly proportional section of the country in which it may occur, the perpendicular heights and horizontal distances being on the same scale. If *a* (Fig. 57) represent the section of a volcano

Fig. 57.



five thousand three hundred feet high; the line *b c*, a portion of country twenty-five miles in length; and *d e*, mountains about two thousand five hundred feet in height; it will be seen that, if we prolong the line, *b c*, about twenty-five miles on both sides, the volcano would soon lose that relative importance which has been purposely here given to it, by making it double the height of mountains on either side.

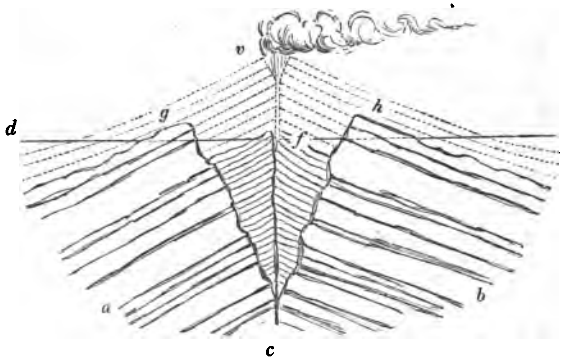
When instead of a single volcano an observer discovers a group of several, he should still keep in view their importance relatively to some given district, until finally he may, as in Iceland, find the whole country composed of little else than volcanic products. By these means he will not over-estimate the value of any given volcano or group of volcanos; neither will he, by thus classifying their relative importance, undervalue any volcanic district he may examine.

b. It has been much disputed of late whether, before a volcano came into activity in a district, the rocks composing the latter were or were not thrust upwards around the place where gaseous, liquid, and solid products were subsequently ejected. To the locality considered to have been raised and fractured by forces acting upon pre-existing rocks from beneath, more at one point than at others, the name of 'craters of elevation' have been given, to distinguish them from 'craters of eruption,' considered to have been afterwards produced by the well-known ejection of ashes, cinders, and lava, which form a conical heap, with a funnel-shaped cavity towards the apex, kept open by the force with which the elastic vapours and gases escape upwards; thus driving ashes, cinders, and lava before them. Craters of eruption are again considered by other geologists to have been mistaken for craters of elevation; and it has been inferred that the observed phenomena may be explained by the shifting of volcanic vents, and the action of a volcano on the small scale in the centre of an area, which had been previously covered by the same volcano when in a greater state of activity, the matter necessary to complete the conical heap, which once covered the larger area, having been scattered during a great volcanic eruption.

To illustrate the theory of craters of elevation, let *a b* (Fig. 58) represent a rock thrust upwards by a force, *c*, acting from beneath with such intensity as to fracture it. It is considered that the elastic vapours and gases, having now a free vent upwards, would pile up successive heaps of ashes, cinders, and lava in a conical form, partly represented by the dotted lines

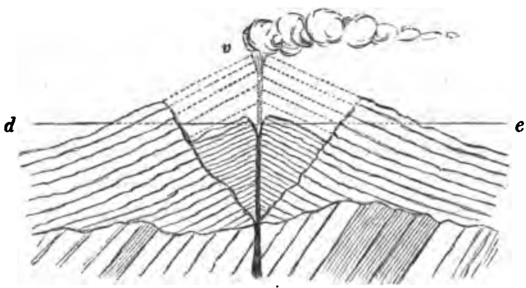
G 5

Fig. 58.



beneath v, and that according to the amount of such accumulated volcanic products would be the appearance of the volcano taken as a whole at any given time. For the sake of better illustration, we have here supposed the first accumulations, from eruptions of cinders and the like, to take place beneath the sea, so that at some given period there may be a volcano, f, existing as an island, surrounded by an amphitheatre of land, g h, forming another island which is circular. It will be evident that, from successive volcanic accumulations, the cavity caused by the fracture of the fundamental rock, a b, will be filled, and that finally it may be entirely covered over and concealed by substances discharged from the volcano. The sketch above (Fig. 58) is only one of many modifications of contorted or broken strata with which cones of eruption may be connected, and to which the name of craters of elevation may be given. To illustrate simple craters of eruption, let a b (Fig. 59) be a mass of rocks, pierced at c by a crack or other

Fig. 59.



shaped rent, which has not upheaved the rocks, *a b*. Then if *d e* be the level of the sea, and ordinary volcanic eruptions take place upwards through *c*, they will gradually accumulate in successive conical layers until they attain any given altitude, such as *v*. It is considered that if all the mass represented by the dotted lines below *v* be now removed by some great volcanic explosion, and the volcano still continue in a state of minor eruption, we might obtain a volcanic island in the centre of an amphitheatre of land.

Before we direct the attention of the observer to particular facts, we should premise that the fractured and upheaved character of the fundamental rock, *a b* (Fig. 58), may be observed in many situations both on the large and small scale among rocks which are not volcanic, and that the occurrence of rocks so situated involves no geological improbability.*

c. The observer should endeavour to ascertain whether there is evidence of strata dipping from a central part outwards in any volcanic district he may examine,

* See "Researches in Theoretical Geology," p. 211.

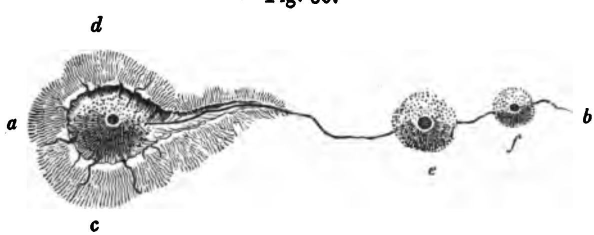
be such district either great or small. Should he find such strata, he should endeavour to trace the continuity of the various beds, distinguishing whether or not they are volcanic. If formed of beds of igneous rocks, such as trachyte, basalt, trachytic or basaltic conglomerates, and the like, he should be particularly careful in tracing them round the volcanic vent or vents; since, if they be completely continuous, without other change than rocks of such characters generally suffer in moderate horizontal distances, or be merely broken by ravines in lines radiating from the volcanic vent or vents as a centre, the evidence would be in favour of a crater of elevation in such particular situation. If the rocks surrounding the volcanic district were not of an igneous character, but such as are commonly referred to an aqueous origin, and they were upturned towards the volcanic vent or vents as a centre, the evidence would also be in favour of a crater of elevation.

Should an observer find a series of beds dipping outwards around a volcanic district, simply composed of cinders, ashes, and the like, with here and there a body of hard rock, such as might readily be considered the section of a lava-current, the evidence would, as far as it goes, be in favour of a crater of eruption; though, as previously shown in Fig. 58, a crater of elevation may still be concealed beneath. There is, however, no reason, that we are aware of, why there should not be numerous simple craters of eruption which are not based on others of elevation, while at the same time there should be numerous volcanic cones, produced by successive eruptions, resting upon craters of elevation, many of which may not be visible. The accumulations

of ashes, cinders, and lava-currents, composing volcanic cones, are merely piles of substances thrown out by elastic vapours and gases at those points where such vapours and gases find vent. It will be evident that such vents may be as readily obtained at points along those great lines of fracture which exist on the earth's surface, as in situations where pre-existing beds of rocks have suffered great flexures and contortions, some of which have been somewhat hemispherical and fractured in their weakest parts, those which are highest and centrical. An observer should direct his attention to the magnitude of a crateriform cavity. If very large,—such, for instance, as that of Deception Island, New South Shetland,* which is five miles in diameter,—the probabilities are against such a crater being one of simple eruption, while relatively small craters may readily be referred to such an origin, in the absence of more direct information, often wanting in islands.

We can very readily conceive the existence both of a crater of elevation, in the centre of which there may be a crater of eruption, and of a crater of eruption without a trace of a crater of elevation, upon the same line of dislocation. Let *a b*, in the annexed sketch (Fig. 60),

Fig. 60.



* Journal of the Geographical Society.

represent a portion of a great dislocation or fracture of the earth's surface, such as are by no means rare in many countries. Let *a* be the point where the fracture may terminate in that direction, the crack becoming a flexure, which, denuded horizontally, produces the circular arrangement of rocks, *d a c*, or circus of elevation, as it is often termed when its dimensions are considerable. If volcanic vapours and gases, struggling to free themselves, find vent at this point, there would probably be a conical accumulation of ashes, cinders, and lava, surrounded by a circular escarpment of rocks, *d a c*, dipping outwards; and consequently there would be a crater of eruption in the centre of a pre-existing crater of elevation. Let *e* and *f* be two other points on the same line of dislocation where volcanic vapours and gases have forced themselves a passage, driving out ashes, cinders, and lava, and we should have two craters of simple eruption without any pre-existing crater of elevation, though we can readily conceive there would be a general tendency to bulge out pre-existing rocks in such situations. The observer will have no difficulty in conceiving many other irregularities and flexures on a great line of dislocation through which volcanic products might find vent; thus accumulating a heap or heaps of ashes, and the like, in the central portions of elevated rocks, arranged in the form of a crater, independently of the action of volcanic power itself, which being directed more to one point than another, might drive superincumbent rocks upwards, and form a large crateriform orifice, in the centre of which a conical pile of ashes, cinders, and lava may subsequently accumulate.

We would particularly advise the observer to study the probability of certain volcanos occurring in lines of dislocation, either straight or curved. The east and west line of volcanos extending across Mexico, and including the modern and suddenly developed volcano of Jorullo, has often been considered a great dislocation of the earth's surface, through which volcanic matter has been ejected at several points of least resistance.

d. The observer should direct his attention to the magnitude of a volcano, as compared with the violence of the eruptions from it. Volcanic eruptions are evidently of different degrees of intensity; but we can readily conceive that a given intensity, produced by any given conditions, may be modified and checked by alterations in those conditions; so that the maximum intensity of the eruptions from a volcano, in the early periods of its existence, may be greater than at later periods,—a given power of elastic vapours and gases having less resistance to overcome after a free vent is first formed, than when such vent is clogged up by a column of lava, cinders, and the like, supported by a large conical heap of cinders and ashes bound together by hard radiating lines of accumulated lava-currents. Consequently, all other things being equal, we should expect more subordinate lateral cones, and fewer eruptions from the central cone, in a volcanic vent which had been long in activity, than from the same vent at earlier periods of its existence. It will be evident, that the observer cannot well infer the relative antiquity of two volcanos, such as Etna and Vesuvius, because the one is larger than the other, and lateral cones exist on the one and not on the other, unless he could show that the

volcanic forces of the one are always equal to the forces of the other, and accumulate equal quantities of matter, producing equal antagonist action, in equal times.

e. Observations on the chemical composition of the various vapours and gases ejected during a volcanic eruption, as well as of those thrown out from crevices and fissures in the crater and sides of the same volcano in a state of minor activity, or of repose, as it is frequently termed, are highly important, because they lead us to a knowledge of the cause of volcanic action itself. It is at present a somewhat prevalent theory, that volcanic action is caused by the percolation of sea, or of other water containing the same salts in solution as those found in the sea, to certain metallic bases of the earths and alkalies. To try the value of this, or of any other theory founded on the percolation of water to volcanic foci, it will be evident that examinations of the vapours and gases evolved from volcanos at various distances from the sea, or other large bodies of superficial water, are important. The observer, if a chemist, will readily proceed to the examination in a manner to ensure success. If he be not a chemist, he may still collect the vapours and gases for examination, by attending to the following instructions:—

He should select glass-bottles to which stoppers have been accurately fitted by grinding; and he may himself grind stoppers into the bottles, or improve their fit by means of fine emery moistened with water. The bottles should then be filled with spring-water (or distilled water if at hand), be emptied as close as possible to the spot whence the gaseous matter is issuing, and then closed before removal from the spot. The stopper

should be first smeared with a thin layer of spermaceti ointment or candle-grease, and its line of junction with the neck of the bottle be covered with cement made of wax melted with half its weight of resin. The stopper should then be tied down tightly with twine. Bottles capable of holding two, three, or four ounces of water suffice for most purposes; but larger ones, if at hand, should be preferred. If bottles with glass-stoppers are not to be had, common wine-bottles and corks may be substituted. The cork should be first softened by percussion between two flat pieces of stone or wood; and when tightly introduced, any portion of the cork projecting above the mouth of the bottle should be cut off, and its surface covered with wax-cement or sealing-wax melted upon it.

f. If there be not too much danger attending the approach to the craters of volcanos at periods of active eruptions, the gases and vapours should be collected at different times during such eruptions, in order to ascertain if any change take place in their character or relative proportions at such times. It is generally considered that carbonic acid gas, when evolved, is thrown out towards the close of some considerable eruption.

g. When practicable, the various sublimations observed in fissures and other situations in volcanic craters should be obtained with care; those liable to deliquesce, or suffer change by the action of the atmosphere upon them, being preserved in bottles with ground glass stoppers and well sealed, so that when subsequently examined they may be as nearly as possible in the state in which they were obtained at the volcano. A comparison of such products obtained from various volcanos

differently situated would assist in advancing our knowledge towards a true theory of volcanic action.

h. With regard to the liquid melted rock, or lava, ejected from a volcano, its chemical and mineralogical composition will necessarily depend upon a variety of circumstances which an observer can have little opportunity of knowing. Its principal character will be that of the mass whence the body of lava is derived, whether such mass be composed of the oxides of certain earths and alkalies then first formed by the percolation of water to their metallic bases, or of liquid heated matter produced by other causes. The depth whence lava is generally derived is probably far beneath the surface of rock exposed to our examinations in the localities where it is ejected. An observer may, however, endeavour to see if there may be any connexion between the chemical composition of the lavas thrown out of any given volcano, and that of the rocks forming the district generally. Portions of rock that are evidently parts of those found in the surrounding districts are ejected from some volcanos. Thus pieces of limestone have been ejected from Vesuvius of the same kind as those forming the surrounding calcareous mountains, so that the volcanic vent probably traverses a subterranean continuation of the rocks composing these mountains, and portions of them are occasionally there broken off. If these had not been suddenly thrown out, they would probably have been melted in the common mass of lava, the carbonic acid being driven off, and the lime combined with silica, rendering the whole mass more fusible from the presence of a larger proportion of silicate of lime. Many argillaceous slates, and rocks of the mine-

ralogical character of those termed grauwacke, may readily be converted into pumice by a little management in our furnaces; so that we can conceive the pumice of the ancient volcanic district of the Rhine to have been portions of the grauwacke of the neighbouring country converted by heat into that substance. It must not, however, be supposed that all pumice is thus derived.

i. It would be desirable for an observer to detach specimens of a fair general character from lava-currents of different ages ejected from the same volcano, in order to see if there be any marked chemical difference in their respective compositions, such as might lead to the opinion that the conditions under which the lava has been produced have varied during the time which has elapsed since the volcano first ejected liquid melted rock.

k. It would also be desirable to observe, among the more ancient volcanic conglomerates, if any such be exposed around a volcano whence portions of non-volcanic rocks are ejected, whether similar portions of rocks be more numerous in them than would probably be the case in the conglomerates now produced around the same volcano; because, if found to be so, there has been a change of conditions under which such fragments of non-volcanic rocks have been thrown out. We can readily conceive, that when volcanic substances are first discharged through a vent situated among non-volcanic rocks, there would be a greater tendency to drive off and eject portions of the latter than when the passage had in some measure been cleared of points of resistance. If the converse be observed,—that is, if portions

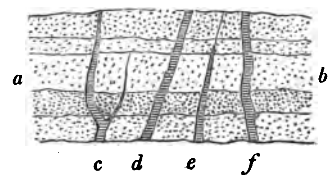
of non-volcanic rocks be not discovered in the older conglomerates of a volcano, while such fragments be now ejected from its crater,—some change of conditions must still have been effected, though produced by other causes than that noticed above as probable.

l. The extent to which fragments of rock, portions of liquid lava, cinders, and ashes may be scattered around a volcano in a state of violent eruption, should be noted, in order that we may duly appreciate the character of the resulting deposit, whether it be effected on dry land, or beneath fresh-water lakes or the sea. The distance to which the lighter ashes may be carried by atmospheric currents is well known to be considerable. It would be desirable to ascertain the chemical composition of such finely comminuted volcanic matter, in order to appreciate any change that may be subsequently produced in or by it, whether it fall upon land or water.

m. The vapours and gases evolved from Solfataras, as they are termed from the Solfatara near Naples, should be examined with care; and the chemical products resulting from their action upon the lavas, cinders, and ashes they may encounter, should be noted. Solfataras may to a certain extent be considered as volcanos in a semi-active state; the relatively small amount of vapours and gases produced readily finding vent, as it were, through a safety-valve, no explosions of highly compressed elastic matter take place, and consequently no piles of solid substances, driven upwards by such explosions, are accumulated at the mouth of the vent in the form of a cone with a funnel-shaped cavity at its apex and down its axis.

n. If the observer study the internal portions of volcanic cones, exposed by various causes to examination, he will frequently find lines of solid rock cutting beds composed of cinders, ashes, and the like, as in the annexed sketch (Fig. 61), in which *a b* represents a

Fig. 61.



horizontal section of conical or other coatings of cinders and the like, traversed by the lines of solid rock, *c d e f.* These lines of solid rock are termed volcanic dykes, and are the result of fissures in the beds *a b,* (caused by the heaves and throws of the volcano during times of activity,) filled by liquid lava, which has either risen or been ejected into them. An observer should examine the mineralogical composition of these lava-dykes, noting how far the same elementary substances may have combined, or been arranged, differently in the matter of the dykes and in that of the common lava-currents of the volcano, in consequence of the different conditions to which they have been respectively subjected. He should also note to what extent, if any, the particles of the ash or cinder beds near the dykes may have been compelled to arrange themselves, when exposed to the heat of the lava filling the fissures, differently from the relative positions they previously occupied, and which relative positions similar particles still occupy in other and con-

tinuous portions of the same beds. The alterations, as they are termed, thus caused, are sometimes highly deserving of attention.

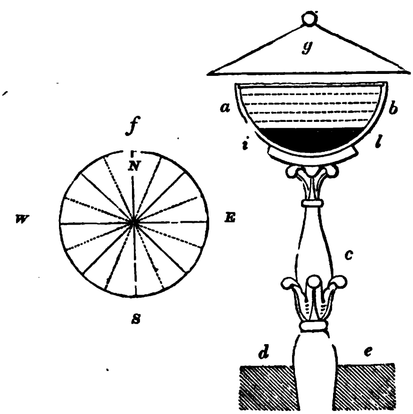
XI. *Earthquakes.*—The geological importance of earthquakes consists in the elevation and depression of land that may be produced by them, particularly when such elevations and depressions take place on the shores of lakes or seas, or across the lines of river-drainage on land, and there is a consequent alteration in the physical features of districts. They also produce cracks and dislocations in the solid surface of the earth.

a. The magnitude of the area agitated by any given earthquake is an object of considerable importance, inasmuch as it is one of the chief elements to be taken into consideration when we search into the cause of earthquakes. It will be obvious that no single person can, from his own observations, estimate the area agitated by an earthquake, though much may be accomplished by the combined observations of many. It is therefore important that a similar series of notes should be taken by various observers, whenever earthquakes occur under circumstances which may enable them to do so.

b. Earthquakes are generally stated to be felt in lines, sometimes in one direction, sometimes in another. It is consequently desirable to learn whether such lines form portions of great curves, and may therefore appear straight for comparatively short distances, or are really straight, as regards any given direction on the earth's surface, for long distances. This knowledge also can only be obtained by the combined observations of several persons. Mr. Babbage has suggested a simple, and,

as it appears to us, certain means, of registering the direction taken by an earthquake. It consists in partly filling some convenient glass-vessel with treacle or other viscous fluid, which, when lateral motion is communicated to it from the earth, is marked in two opposite directions by the wave produced in the treacle or other viscous fluid. A line drawn across the two highest and opposite points marked by this wave would give the direction of the shock by which it was produced.* If instruments founded on this principle were constructed alike in every respect, we might not only obtain the

Fig. 62.



direction of earthquakes, but some information respecting their intensity at different places. Let *a b* in the annexed sketch (Fig. 62) be a hemispherical basin of a

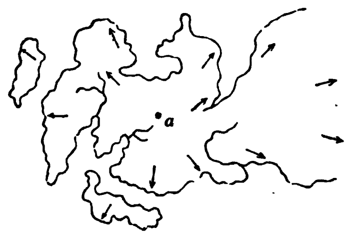
* "Economy of Manufacturers," 2nd edit. p. 58.

given size, formed of glazed earthenware or glass, as may be considered most convenient, filled up to the height *i l* with treacle or any other substance considered most likely to attain the end desired. Let equidistant horizontal lines be marked in the interior of the basin from the treacle to the rim; and let the basin be tightly fixed upon a perpendicular pedestal, *c*, driven firmly into the ground, *d e*, in some sheltered court or garden, away from any vibrations produced by accidental causes in a dwelling-house, and from the fall of any building upon it during an earthquake. To keep the interior of the basin clean and free from insects, a circular glass disc should cover its rim exactly; and in order to render this disc still further useful, the various points, North, South, &c., should be correctly marked in lines, as at *f*, upon it, so that the lines of the disc being arranged to correspond with the *true*, not the compass, North and South, the direction of the wave produced by the shock of an earthquake may be at once seen, without first disturbing the basin. In situations where sufficient protection from the weather is not afforded to the instrument, a conical covering, *g*, should be supplied. Such instruments would essentially cost but little, and might be extensively employed in countries agitated by earthquakes. By their means we should not only obtain the direction of shocks, but some information as to their intensity, as far at least as a greater or less waving motion of the earth was produced, by the relative height to which the treacle or other viscous fluid might rise in the basin.

c. Supposing the above or any other convenient instruments constructed for similar purposes were exten-

sively distributed, we might eventually learn whether, as in the annexed sketch (Fig. 63), supposed to represent some given portion of country, there was a point,

Fig. 63.



a, from which the various shocks seemed to radiate, decreasing in intensity as they receded from *a* as a centre; or whether, as in Fig. 64, they followed a long marked

Fig. 64.

line of direction, *a b*. In the first case, we should have a centre of disturbance, and consequently the cause of the earthquake produced vibrations around it. In the second, we do not know that any portion of the superficies of the globe has been so acted on as to produce vibrations from a central point of some part of such superficies outwards. The vibration may merely have run along a line of some great previous fracture of the earth's crust, upon which a force acting upwards, from a

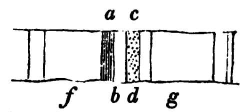
situation deeply seated beneath the surface, would more readily produce vibrations, from the comparatively less resistance of parts in that or similar lines, than in portions of the earth's surface not so fractured. As it is no part of our object to press particular theories upon the attention of the observer, we must refer to geological works for those which account for earthquakes, leaving him to adopt such as may appear the most probable. He will perhaps come to the conclusion, that the vibrations of the earth's surface, commonly termed earthquakes, may be due to more than one cause. If so, he will expect a difference in the effects produced, and consequently look to detailed observations, made with the best means in our power, for those facts which, being subsequently classified and duly weighed, may ultimately lead to the knowledge required.

d. Let earthquakes be caused by what they may, the vibrations produced by them will be modified and disturbed by the nature of the substances through which they pass. An observer, therefore, should direct his attention to the compactness or other characters of rocks in districts agitated by earthquakes. A force acting with a given intensity may produce very different vibrations in rocks of different structures, and the force may in some cases be just sufficient to cause vibrations in one rock and not in another, so that an earthquake may be felt in the line of one rock and not in another. As, however, the effects resulting from this cause would greatly depend upon the relative position of the rocks, due care should be paid by the observer to this circumstance. Rocks also piled horizontally upon each other might transmit vibrations through them more readily in

that position, from the action of a given force, than when the same rocks were in a perpendicular position and acted on by the same force; because, in the latter case, the resistance would probably be greater than in the former. Let *a*, *b*, *c*, *d* (Fig. 65) be four rocks lying

Fig. 65.

Fig. 66.

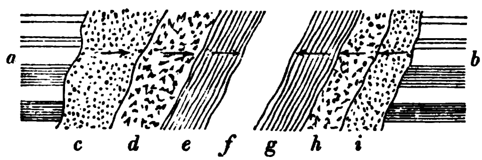


horizontally upon each other, and acted on laterally by a force at *e*, then there would be less resistance to vibrations than when the same rocks were placed vertically and bound in by other masses of rock, *f*, *g* (Fig. 66), and the same force acted laterally upon them in the direction of the eye of the reader.

An observer should endeavour to trace whether there be any coincidence between the general direction of mountain ranges and that of earthquakes, as also whether there may be any such coincidence between prevalent shocks and the direction of strata generally in a district, such strata not having been forced up into mountain chains. He should, however, recollect that the general direction of a mass of rocks, composing a portion of the earth's surface, may be masked by more modern accumulations, and therefore he should endeavour to ascertain if there be any probability of such older rocks running in lines beneath the more modern deposits. For if lines of direction, in stratified rocks, could influence the line of shocks in an earthquake, and the cause of the earthquake act from beneath, such influence

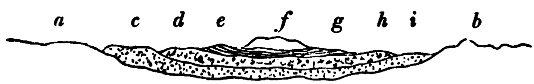
would be first exercised by the direction of the lowest rocks, and tend to modify the vibrations produced in those above them. Let *a b* (Fig. 67) be a stratified

Fig. 67.



rock, such as grauwacke for instance, and let it have an east and west direction, and contain in a trough-shaped cavity other rocks, *c i*, *d h*, *e g*, and *f*, in such a manner that a vertical section would show them to occur as represented in Fig. 68, where the same letters

Fig. 68.



mark the same rocks as in the horizontal plan, Fig. 67. And further, let the outcrop, or rising of strata to the surface, be such, that the lines of the outcrop and directions of the beds of the rocks *c i*, *d h*, *e g*, and *f*, be N.N.E. and S.S.W. nearly. Then if shocks of an earthquake be found to take an east and west direction, at any situation upon the rocks *c i*, *d h*, *e g*, and *f*, it should not be too hastily concluded that they are not influenced by the direction of strata beneath, because the superficial rocks have a direction N.N.E. and S.S.W.; since, in this case, the shocks in question, if influenced by the direction of the lower rocks, would

coincide with the direction of the strata of the rocks *a b*, because they would be first acted upon.

e. If after earthquakes there be reason to consider that land has either been raised or depressed by the shock or shocks, great care should be taken to ascertain correctly the amount of such rise or depression. For the most part, the general sea-level is that which is not only the most convenient, but most certain, for purposes of comparison. To produce any great change in it by any cause which can alter its level, there must be such an amount of solid matter moved up or down beneath the ocean, that the term earthquake, as usually employed, could not apply to such an exercise of subterranean force, be the cause of the force what it may.

An observer should most carefully measure any rise or depression of a coast, produced by an earthquake, with the mean surface-level of the sea before and after the event; the exact difference between the two being the true measure of the rise or depression, as the case may be. It is probable that by a due attention to exactitude in this respect, proper allowances being made for the variable height of tides where such occur, and for the influence of winds in locally raising or depressing the sea-level at a time of observation, the rise or depression of land from earthquakes would sometimes be found greater and sometimes less than the measures often given.

It is necessarily a difficult process to trace any such rise or depression inland, unless the country be one in which the height of a variety of points, above the sea-level, has been ascertained with exactitude, when any change in their relative heights would afford that of the

rise or depression caused by an earthquake. There is scarcely a country the heights of which are measured with such precision as to afford exact data for this purpose; though there are, no doubt, some countries of which certain points seem to have been most accurately ascertained. If, however, the general drainage of a country rise inland, as is commonly the case, observations on the velocity of rivers would be found valuable, when their previous velocities are known, as sometimes happens, to a certain extent, where mill-dams or other obstructions cross a river, and, consequently, where any change producing a greater or less slope in the river-bed is soon detected. It is extremely desirable to obtain precise information upon this subject; for, hitherto, calculations intended to give an idea of the cubic contents of masses of land, either raised or depressed by any given earthquake, have not rested on such data as could be desired. They may readily have been either greater or less than those calculated.

f. Although it would generally be exceedingly difficult to estimate the depth to which any given line of coast may have been depressed beneath the sea-level by a succession of earthquakes, unless sufficient historical documents exist to do so, the height to which it may have been elevated by such means may be inferred, if an observer discover a series of beaches elevated above each other on a coast known to have been raised by any earthquake, the last beach having been clearly elevated by such means. Due care must, however, be taken to estimate the value of other causes which may have produced the effects observed.

g. In cases where the bottom of the sea is considered to have been raised by an earthquake, and a neighbour-

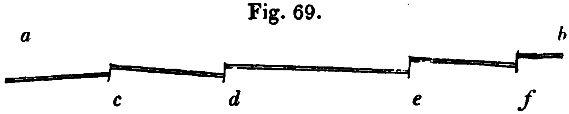
ing volcano has been in a state of activity at the time, an observer should endeavour to ascertain if any considerable amount of ashes and cinders has fallen into the sea in the situation where the bottom has been supposed to have been thus elevated. He should also direct his attention to the sea-level on the adjoining coast. If there be no relative change as regards the level of the sea-line on the coast, and there has been a considerable fall of cinders and ashes in the locality considered to have been raised, the supposed rise caused by an earthquake is probably deceptive. Even on coasts where there has been no fall of volcanic substances, proper allowance should be made for the addition to beaches in favourable situations, produced by the great breakers generally discharged with great fury on coasts during earthquakes. These accumulate a great body of detritus in such situations, upon the same principle that the breakers, during a heavy gale on shore, accumulate greater beaches in front of low land than in more moderate weather. Proper attention should also be paid to the probable accumulation of live molluscs, corals, &c., by such breakers, the result of waves which tear up the sands and mud, and break off portions of corals, sea-weeds, &c., and discharge them on shore, on the same principle that minor breakers and waves near coasts do so during gales of wind. We are desirous to place an observer on his guard where circumstances may be equivocal, and that, under such circumstances, the mere addition of height to a given beach, or a long line of accumulated live molluscs, &c., may not be considered good evidence, in the absence of better, of a rise of land from an earthquake in that particular situation.

h. It can scarcely be expected that during those

earthquakes where rents and fissures are produced in the ground, an observer can calmly direct his attention, amid the danger which surrounds him, to the gases or vapours which may escape from such rents and fissures. He may, however, be conscious of any particular odours that may escape from the fissures, as also of any appearance of flame. The latter is sometimes stated to have been witnessed; and if the appearance has not been deceptive, it is desirable to possess such data respecting it as may lead towards a knowledge of its cause. The exact amount of dislocation of rocks caused by an earthquake should be carefully noted; and the number of feet which one side of a fissure may rise or fall above or beneath that of the other should be ascertained, observing whether such relative change in the level of the rocks on either side be produced by a rise or fall generally of the land around. It is exceedingly desirable that all such changes be measured, and the exact measures recorded; and that they be not merely described as 'enormous!' 'stupendous!' and the like, when, perhaps, a change of level produced in the two sides of a fissure, and thus characterised, may not be more than from four to ten feet. When noticing such terms, we cannot but express a hope that they may be omitted in geological descriptions, since they convey no definite ideas of height, depth, or distance, and lead only to vague, and, for the most part, exaggerated, notions of things which can readily be measured. We once measured, and reached the bottom of, a 'fathomless abyss,' with a line of about ninety feet! and have seen 'enormous dislocations,' so trifling that they were difficult to discover.

i. The direction of any fissures or ridges of raised ground, caused by earthquakes, should be carefully observed, and their length and breadth as accurately noted as possible. Whether they run in lines parallel to each other, or radiate from some central point, should also be ascertained; and whether, if parallel, the dislocations have been effected in the manner represented in the annexed imaginary cross section (Fig. 69), where the

Fig. 69.



surface of a nearly level tract of land, *a*, *b*, has been so dislocated in parallel lines, *c*, *d*, *e*, *f*, that three ridges and depressions have been produced. All changes and their probable consequences in the physical features of a country, either ridged, furrowed, or otherwise altered by the effects of earthquakes, should be noted; and when numbers can be used to convey definite ideas of such changes, they should be employed. Thus, instead of informing us that the course of a river has been arrested by an earthquake, that a lake has been the consequence, and that this lake, when it 'bursts,' would excavate valleys, &c., we should be informed whether a river had been stopped by the fall of loose rocks and other substances in a ravine or other situation where such an effect could be produced, or whether a ridge caused by an earthquake had dammed back the waters of a river; in either case, giving us the height, breadth, and composition of the dam. When accumulations of water are produced in consequence of rivers arrested in

their progress, we should have some definite description of their length, breadth, and depth, and consequently of the body of water they may contain; so that, when it is inferred that valleys may be excavated by the 'bursting,' as it is termed, of such lakes, we may be enabled to judge of the manner in which the waters may obtain a passage through the dams, and of the probable effects which may be thus produced.

XII. *Gradual rise or depression of large tracts of land, unaccompanied by shocks of earthquakes or other sudden movements of the earth's surface.*— For more than a century it has been observed that a change was slowly taking place as regards the relative position of sea and land in parts of the shores of Sweden bathed by the Baltic; and Von Buch long since asserted that the surface of Sweden was gradually rising from Frederickshall to Abo, and that such rise probably extended into Russia. Of late this important circumstance has received that further attention that it deserved, and it has been asserted that the rise of land was unequal, taking place more on the north than on the south.

a. When such an elevation of land is suspected, observations to ascertain the fact should be conducted with great care, and with due regard to those local circumstances which may affect them. It is evident that, in the first place, proper marks should be made on cliffs or other sufficiently stationary objects, showing the height of the sea-level as regards the coast at some given time. To fix upon such level is no inconsiderable difficulty, in tidal seas especially: Even considering that tides, taken by themselves, so occur that a mean might be obtained of their height at any given place, it scarcely

happens that they are not modified in their exact height by the pressure of the atmosphere at the time, and by the state of the winds generally in a considerable area around the given locality. After the prevalence of a strong wind on shore for some time, it frequently happens that high water is kept up beyond the proper time in harbours, and the level of the tide is forced up, even to as much as two or three feet, beyond what it would have been if there had been no strong prevailing wind on shore. When a strong off-shore wind continues for some time, the reverse happens; and what is thus true of high water is also true of low water. These effects are again modified by the state of the tides at the time; much depending upon their being springs or neaps, as they are technically termed.

According to Captain Denham, the mean between high and low water of every tide affords a constant level in the same locality. Observers should, therefore, obtain the mean height between high and low water in *calm* weather, and affix proper marks on cliffs in favourable situations. Supposing a correct level could be thus obtained, it would be highly valuable for observations on tidal coasts respecting the gradual rise or fall of large tracts of country.

b. In tideless seas, such as the Baltic and Mediterranean are commonly termed, though they cannot obviously be strictly so, similar precautions as regards the pressure of the atmosphere and the state of the winds during an observation are necessary, otherwise very serious errors may be committed. It is well known that the Baltic is kept up at least two feet by a strong and continued north-west wind; the Caspian sea is higher by several feet at either end according to the prevalence of

a strong north or south wind; and it is equally well known that the height of the sea in the ports of the Mediterranean is greatly influenced by the state of the winds for the time.

c. In noticing the foregoing sources of error, we by no means intend to throw doubt on the probable slow rise and depression of land now taking place in various parts of the earth's surface: on the contrary, we believe that they do occur more generally than has been hitherto supposed, and we have repeatedly stated our opinion that such gradual rises and depressions of the solid part of the earth's surface are necessary to explain many geological phenomena observable in the fossiliferous rocks, as well ancient as modern.* We merely desire to call attention to certain necessary precautions, when a given locality or line of coast is under examination, so that, in the first place, there may be a certainty of the locality or of the coast rising or sinking, as the case may be; and in the second, that, if the one or the other be matter of fact, there may be no error in the *amount* of elevation or depression stated to take or to have taken place in a given time.

XIII. *Temperature of the Earth.*—We include under this head observations on the temperature of rocks, &c. in mines, and on the temperature of seas, lakes, Artesian wells, and springs. We shall abstain from pressing particular theories upon the attention of the observer, leaving him to adopt such as may appear to accord best with the phenomena he may notice.

* See "Geological Manual," and "Researches in Theoretical Geology."

a. In observations of this kind it is essential that the thermometers employed should be of the best possible construction,—not graduated in the common way by merely noting the freezing and boiling points of water at a given height of the barometer, and then marking a certain number of equal parts between these points, according to the scale adopted; but by carefully verifying the graduation at numerous points with standard thermometers, constructed with every requisite care. In delicate observations of this kind regard should be paid to the age of the thermometer itself, since it has been found that in mercurial thermometers the freezing point slowly rises after graduation; and as the principal effect is produced soon after the tube is sealed, it has been recommended that some months should elapse between the sealing and graduation of a thermometer.

b. The numerous sources of error which may influence observations on the temperature of the air or water in mines or collieries, though they may be conducted by very skilful and experienced persons in such a manner as to ensure success, when the sources of error are duly considered, are such that more direct observations should be preferred whenever practicable. Great care should obviously be taken to avoid any source of error either in the instruments or other means employed. The following was the process adopted by M. Cordier, who has given great attention to this subject, when he obtained the temperature of the rock itself in some coal-mines of France:—The thermometer was loosely rolled in seven turns of silk paper, closed at bottom, and tied by a string a little beneath the other extremity of the instrument, so that so much of the tube might be withdrawn as might

be necessary for an observation of the scale, without fearing the contact of the air; the whole contained in a tin case. This was introduced into a hole from twenty-four to twenty-six inches in depth, and one inch and a half in diameter, inclined at an angle of 10° or 15°; so that the air once entered into the holes could not be renewed, because it became cooler and consequently heavier than that of the galleries. The thermometer was kept as nearly as possible at the temperature of the rock, by plunging it among pieces of rock or coal freshly broken off, and by holding it a few instants at the mouth of the hole, into which it was afterwards shut, a strong stopper of paper closing the aperture. The thermometer generally remained in this hole about an hour.*

Observations have also been made by drilling a hole, a yard or other convenient measure in depth, in the rock of a mine, and observing the temperature during any given period, such as a year or more. It may be stated, that from the observations hitherto made on the temperature of the rocks in mines, and, even with every allowance for error, on that of the air or water of such situations, there is an increase of temperature downwards from that depth where changes of temperature are not produced by the climate to which the actual surface is exposed. It is scarcely necessary to state, that observations should be made on rocks at various depths, and in situations as little as possible under the influence of heat occasioned by the presence of miners with their lamps or candles, by the blasting of gunpowder, or by a mixture of iron pyrites, water, and

* Essai sur la Température de la Terre: Mém. de l'Acad. tom. vii.

shale, where such occur. It is also desirable that the observations should be made as remote as possible from lodes or mineral veins themselves, in which there may be obvious causes of error, and in the driest parts of mines.

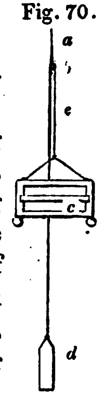
c. Observations on the temperature of the sea at different depths may for the most part be made with those thermometers commonly termed register, in which the graduated tubes are placed horizontally, a mercurial thermometer pushing forward an index to the greatest heat to which the instrument has been exposed in the sea, while an alcohol thermometer draws back on another index to the greatest degree of cold to which it has been subjected; so that the observer learns the extremes of temperature to which the whole instrument has been exposed after it quits the surface. Observations, therefore, at considerable depths might be considered uncertain with such an instrument, if care be not taken to obtain the temperatures of the sea at various intermediate depths, since changes might have happened at such various depths, and the register thermometer merely marks the extremes of temperature to which it has been subjected. There are various other instruments, a knowledge of which an observer may readily obtain at the best philosophical instrument-makers, contrived for the purpose not only of taking the temperature of the sea at various depths, but also of obtaining water at the same depths.

Of whatever kind the instrument employed may be, in all those in which the temperature of the water is not taken after a portion of the latter has been withdrawn from any given depth, but in which a thermometer is made to descend in the sea, it is necessary that the materials of the instrument employed, viewed as a whole,

should be such as readily to take the temperature of the depth to which it may be plunged, and that the thermometer should have some contrivance for registering the temperature; since the same materials which speedily take the temperature at various depths, as readily permit the thermometer to be affected by changes in the temperature of the water when drawn upwards to the surface.

In cases where an observation may be rendered uncertain by a shock of the instrument employed upon the bottom of the sea, when such bottom may be touched by the length of line to be run out, it is desirable to have the sounding lead so arranged, with respect to the instrument for obtaining the temperature, that when the former touches the ground, the line may be held firm and the lead raised above the bottom, so that the jerks, which might be caused by the pitching or rolling of the ship or boat above, and derange any index for registering temperatures, may be as much as possible avoided. We have often arranged the line, instrument, and sounding lead upon the principle represented in the annexed woodcut (Fig. 70), and have found it answer the purpose intended:—*a* is a line leading up to the boat or ship; *b*, a point where another line, *e*, supporting the instrument for ascertaining temperatures, *c*, is attached to it; the main line, *a*, being continued down to the sounding lead, *d*. The line *e* supporting the instrument may be of any convenient length, and that of the main line, from the point *b* to the sounding lead *d*, either ten, one hundred, or any other number of feet, as an observer may think proper.

Fig. 70.



It will be obvious, that when the lead *d* touches the bottom, and is felt by the person sounding, the line should be held firm, so that the instrument does not strike against the ground. If the bottom of the lead *d* be armed, as it is termed, in the usual manner, the temperature of a given depth, the actual depth of the sea at a given place, and the kind of bottom, are all ascertained at the same time.

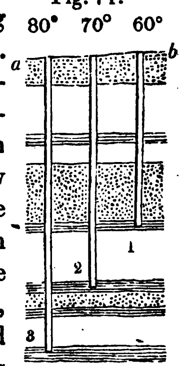
d. Observations on the temperature of the sea are to a great extent simplified by the fact, that sea-water attains its greatest density at about the temperature that it becomes ice; so that in situations such as the tropics, where the surface temperature never approaches that of the freezing point of water, there would be a constant decrease of temperature downwards, and the lowest temperature would not be so low as the freezing point of sea-water. In the colder regions of the globe, where the surface-water is so exposed to temperatures producing densities which may either cause it to keep its place or descend, within a small range of the thermometer, variations of temperature will occur which it will require very great care on the part of the observer to ascertain.

e. The temperature of lakes of fresh water may be obtained with the same instruments and in the same manner as that of the sea. Such observations are, however, rendered still more simple by the knowledge of the fact, that fresh water attains its greatest density at a temperature of between 39° and 40° of Fahrenheit's scale, and consequently that all fresh water of a greater or less temperature will float above water of that temperature. The observer should direct his attention to

the depths to which the variations in the heat of climates extend in deep lakes, endeavouring to ascertain those beneath which the temperature remains nearly the same throughout the year, under ordinary circumstances.

f. It has been found that, viewed generally, the temperature of the waters rising to the surface in those perpendicular perforations into the earth, named Artesian wells, increases with the depth whence the water has been derived. If allowed to remain at rest, the waters in such perforations would endeavour to arrange themselves according to their relative specific gravities, and therefore according to their densities, the warmest water being uppermost, considering the whole column of water to be above 40° Fahrenheit. Consequently, according to the original temperature of the water beneath would be the observed temperature above, and therefore if comparatively warm waters were found at the top of the deepest perforation, even when the waters did not flow over the surface, the original temperature of such waters would increase according to the depth of the Artesian well. Let 1, 2, 3 (Fig. 71), be three Artesian wells of different depths, perforated perpendicularly downwards from the surface, *a b*: if an observer now find the respective temperatures of the surface waters of these wells, even when they do not flow over the surface *a b*, to be, for the sake of illustration, equal to 60°, 70°, and 80°, he would have evidence that the temperatures depended upon the depths, all other circumstances be-

Fig. 71.



ing equal, notwithstanding he might procure more equal temperatures by sinking towards the bottom of each well.

Artesian wells, however, generally flow over the surface from which they are perforated; indeed their economical value depends upon this circumstance. The force with which they rise is commonly such, that the water cannot arrange itself in the perforation or pipe according to relative specific gravities; so that, when it reaches the surface, particularly after the flow has continued some time and the sides of the Artesian well have acquired their proper temperature, the water will be nearly of the temperature of the deep-seated source whence it is derived. An idea of the force with which the water rushes to the surface in some Artesian wells may be formed, when it is stated, that in one formed at Tours, and perforated to the depth of eighty-eight feet beneath the level of the Loire, the water rises to from thirteen to sixteen feet above the surface of the land, with such force that a tin cylinder containing twenty-two eight-pound balls was thrown out when introduced into the perforation. In such a case there would be little chance of error by considering the temperature of the water, when it comes to the surface, to be that of the same water at the depth of eighty-eight feet.

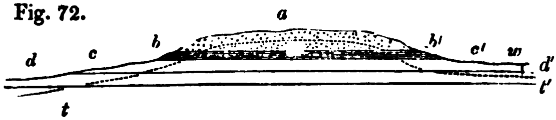
An observer should be on his guard against the possibility of some of these waters being thermal, and that they may have been prevented from rising in the usual way to the surface by the gradual accumulation of beds of rock, which, having been artificially pierced, permit a portion of the waters to escape. We notice this, in case it should ever be observed that the temperature

of Artesian wells, which discharge a large volume of water in a given time, should be found to rise slightly, which we might expect if thermal waters gradually acquired a more free passage to the surface than they at first possessed. If thermal waters rose to a surface considerably beneath that of the soil in any given district, and there spread out in tabular sheets between strata, it will be evident that they would eventually take the temperature of the strata between which they occur; and, therefore, if they are subsequently and suddenly conveyed to the surface by artificial means, they will afford the temperature of rocks at known depths.

g. It having been considered that common springs in the tropics possess temperatures lower than those of the climates in the same localities, and that those of the cold regions of the globe are, on the contrary, higher than the mean of the climates in such situations, it becomes important to ascertain the temperature of common springs with precision, in order to see how far the facts may be general. If they be general, there will be some modifying influence distributing a more uniform heat over a certain depth beneath the earth's surface, than would appear probable from the mere effect of solar influence. As very great exactitude is necessary in observations of this kind, every care should be taken duly to estimate any causes of error which may present themselves.

In the first place, the observer should, if possible, ascertain the condition under which the springs exist. Some modification of the conditions represented in the annexed vertical section (Fig. 72) is not uncommon. Let *a* be a porous rock—a slightly aggregated sandstone,

Fig. 72.



for instance—resting on a bed, *b b'*, nearly impervious to water, such as clay; then rain-water falling upon the top of the hill is in a great measure absorbed by the porous rock *a*, but its progress downwards being checked by the clay, or other nearly impervious bed, *b b'*, it comes filtering out in the shape of springs on the side of the hill at the level *b b'*. Let us, for further illustration, suppose another porous rock, *c c'*, to occur beneath *b b'*, and that in its turn it is supported by a bed of rock nearly impervious to water, *d d'*; then the rain falling upon the rock *c c'*, will be first absorbed and afterwards filter out in springs on the side of the hill at *c*, but not at *c'*, because the nearly impervious bed *d d'* is not exposed on the surface in that direction. But if a well, *w*, be sunk on that side of the hill, the same water will evidently be obtained as at the junction of the beds *c* and *d* on the other side of the hill. The water in these cases is first at the temperature that it takes in the atmosphere; but percolating through the rocks which absorb it, it becomes of their temperature. Now, if these rocks vary in temperature according to their depth beneath the surface of land, there would be a line of uniform temperature, represented by the dotted line *t t'*, parallel to, and beneath, the actual surface, *d c b a b' c' w*; and consequently, if water percolates slowly to the surface in the shape of springs, it would probably take the temperature of the rocks, all other things being equal, between the line *t t'* and such surface; whereas, if

it rose more rapidly, it might carry with it the temperature of lower depths, in proportion to the volume of water discharged and the velocity with which it was so discharged. Hence the quantity of water delivered by a spring in a given time, and the rapidity with which it rises, require to be duly estimated.

Other springs again are evidently not modifications of the above conditions. They sometimes rise from dis-

Fig. 73.

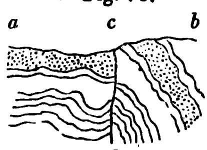
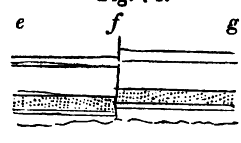


Fig. 74.



locations of rocks, commonly termed *faults*; such are represented in the sections above (Figs. 73, 74), where *f h* represents a dislocation of nearly horizontal rocks; *c d*, another dislocation of disturbed rocks. In such cases we cannot be certain that the waters, rising through the fissures *c d* and *f h*, to the respective surfaces *a b* and *e g*, may not be derived from great depths, and bring the temperatures of such depths with them to the surface, modified by any change they may suffer in rising upwards, such change depending, as we have before seen, upon the rapidity with which their rise can be accomplished, the volume of water being duly considered. This caution is the more necessary, since warm or thermal springs commonly appear to rise through fissures, and would in such cases necessarily be modified in temperature according to obvious circumstances.

Springs in limestone countries frequently rush out with great force: they may in some instances be termed small rivers. This arises from the cavernous character of such districts, and the generally ready manner in which rains are swallowed up in cavities communicating with the surface; often also from the highly tilted character of the beds in such districts. In the great tract of country formed of compact white limestone in Jamaica, this fact is remarkably exhibited. Notwithstanding the heavy fall of tropical rains in that district, nearly the whole is immediately swallowed up by innumerable holes and caverns, which join in subterranean passages; so that a spring, properly so called, can scarcely be seen for considerable distances, while here and there a small river rushes to-day from amid the rocks. To judge of the temperature of the earth, at those relatively small depths where climate ceases to have an influence, by that of such waters, will depend upon the time the latter may have remained beneath among the rocks, so that they should acquire their temperature.

The observer should therefore weigh well the conditions under which the springs he may examine come to the surface, and, when he notes their temperatures, should also note so many of such conditions as he can ascertain. In this manner we should ultimately obtain several series of classified facts, and consequently be not only enabled to judge of the relative value of each series, but also of the whole viewed generally. It is necessary to caution an observer against one circumstance which, from experience, we have found to require much attention. In taking the temperature of a spring, he should

clear away the ground so as to get as near as possible to the spot where the water actually rises from among the rocks. Without this precaution, an error of two or three degrees may readily be committed. In thermal springs it is especially necessary, particularly when the volume of water discharged is not considerable. The thermometer should also be introduced into the aperture whence the spring rises: and if the observer be accustomed to handle delicate instruments, he will find one of those thermometers in which the bulb and a portion of tube project beyond the graduated scale most useful, as well as most likely to afford accuracy.

XIV. *Gaseous Exhalations.* — Gaseous exhalations are observed in many parts of the world in situations which cannot be strictly termed volcanic. Indeed, in some places where such exhalations are observable, there is no trace of modern, or comparatively modern, volcanic action within considerable distances. As these exhalations are evidences of chemical action beneath the immediate surface of the earth, correct observations on their nature and the conditions under which they apparently exist become important.

a. When jets of gas escape through fissures of rocks into the atmosphere, the observer should carefully collect a portion of such gas in the manner recommended (p. 136) for the gases and vapours ejected from volcanos. He should, if circumstances permit, take a general view of the structure of the surrounding country, in order to see how far it may assist in affording information as to the cause of any gaseous exhalation under examination. Suppose, for instance, the gaseous exhalation examined should turn out to be one of car-

buretted hydrogen, and the district in which it occurred was composed of rocks containing beds of coal, there would be no very great chance of error in assuming that the gas was probably evolved from the coal-beds. Again, it having been remarked that inflammable gas often appears in the vicinity of saline springs, the observer should direct his attention to this circumstance. Salses or mud-volcanos, as they are termed, seem the result of chemical action during which much gaseous matter is evolved. Observations should be directed to the conditions under which they occur, and particular attention should be paid to collecting the gaseous products.

b. Gaseous exhalations often bubble up through water. In this case, an observer should take a bottle (of the kinds previously noticed, p. 136), fill it with water, and then invert it with its mouth under the surface of the water through which the gas bubbles up, so as to receive the latter before it enters the atmosphere. A piece of writing-paper, or a large leaf, may be rolled up into the form of a funnel, and serve to direct the gas into the mouth of the bottle. The bottle should be then stopped or corked, and sealed in the manner previously recommended (p. 137).

c. It may be here remarked, that in collecting mineral or thermal waters, which are frequently accompanied by gas, care should be taken to collect as much of the latter as possible. Instead of bubbling up freely, the gas sometimes escapes almost imperceptibly; in which case, a bottle alone would be of little assistance; therefore a vessel having a large opening beneath should be employed, so as to offer a larger surface to the gas rising

upwards. Such a vessel should be secured and left with its lower rim beneath the surface of the water, so that when the water which was contained in it, before it was inverted, is nearly displaced by the gas, it will merely require a little dexterity in transferring the gas into bottles; the larger vessel being held beneath the water, and the gas permitted to escape from it in bubbles into the mouth of a bottle previously filled with water and inverted. In this way an observer may obtain fair results even without the aid of an apparatus especially contrived for the purpose. It is particularly important to ascertain if nitrogen be always evolved from thermal springs. Even when circumstances will not permit more than a hasty examination of a thermal or mineral spring, gas contained in the water may often be secured, if an observer fill a bottle with the least possible agitation. The bottles should be all but filled with the water, and the cement (previously noticed, p. 137) applied immediately after the cork or stopper is inserted.

XV. *Submarine forests.*—In various parts of the coasts of Great Britain, Northern France, and Germany, collections of trees of species now existing, various plants, leaves, nuts, &c. are detected at levels beneath that of high tides, frequently running out to sea, so as to be exposed only at low water. These have received the name of *Submarine forests.*

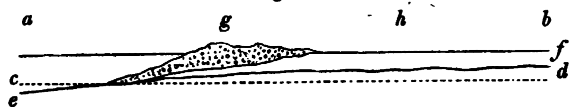
a. As some geologists consider that a change in the relative level of the land and sea in such situations is necessary to explain the facts observed, while others suppose that the trees, &c. may have grown and have

been collected in lower situations than that of high water, which was barred out by a line of beach, an observer should be very careful in an examination which requires so much minute accuracy.

In the first place, he should take levels of the locality, and see what depth, if any, the line of trees, &c. or of the submarine forest—to comprise the whole in two words—is beneath that of high or of low water, for the latter sometimes happens. He should then endeavour to ascertain if there is evidence of any portion of the submarine forest having grown on the spot where it occurs. In some cases this will be difficult; but in others he will find the roots of trees firmly planted in the ground, and the whole character of the accumulation such, that he can have little doubt that the leaves, branches of trees, &c. have been collected around the roots. We here suppose that there can be no doubt that the plants and trees are such as now exist, even in the neighbourhood, for the observer must be on his guard against similar effects which may have been produced at former geological epochs.

b. He has now to consider the general conditions of the locality, whether it be in front of a valley, of a larger tract of flat land, or otherwise. Let us suppose, for the sake of illustration, that the annexed diagram (Fig. 75) represents a longitudinal section of one of these submarine forests; *a b* being the level of high water, *c d* that of low tide; *e f*, the line of the submarine forest; *g*, a beach thrown up by the sea; and *h*, sand, silt, or clay covering up the bed *e f*. In this case the forest would alone be exposed on the shore at

Fig. 75.



low tide, and an observer would only be aware of its existence inland by artificial or natural sections which should cut through *h*. Now if roots of trees retain the places in which they grew, not only in the seaward front of the beach *g*, but also behind it, and the beach itself be found to rest upon a continuation of the forest, the beach has evidently been accumulated after the growth of the forest; and if any other beach once kept the sea away from the trees near *e*, such beach has disappeared. An observer has now to see if the beach *g* rests upon *h*; because if it does, then *g* has been accumulated after the formation of *h*. He should next endeavour to ascertain if *h* has been deposited in consequence of checks offered to the progress of fresh water charged with detritus seaward, or whether it has been produced by deposition from detritus mechanically suspended in sea-water. This observation is often difficult, except organic remains be present in *h*, when it can be ascertained whether they are of fresh-water or marine origin. In the illustration before us—which we have given because we have found it somewhat common, and not with the desire of pressing any particular views upon the reader—the order of events would be: 1. Land so situated that terrestrial plants, such as oak, yew, fir, &c. could grow, mixed sometimes with marsh plants; 2, The growth of the plants and trees, many evidently

to considerable sizes; 3. A relative change of circumstances, by which sand, silt, or mud was accumulated in a bed upon broken stumps of trees, &c.; 4. Another change of circumstances, by which the sea acted upon one side of the vegetable accumulation, laying it open beneath the level of the tides, cutting back its former covering of mud, silt, or sand, and piling up a beach which, under ordinary circumstances, bars any further attack upon that portion of the forest which remains still covered by its coating of mud, silt, or sand.

c. Correct observations on the substances, such as gravels, sands, and the like, collected above the inland portions of submarine forests, are highly valuable. Evidence is sometimes thus afforded of more than one change of the conditions which have preceded the final appearance of the submarine forest and associated beds, under the circumstances which now present themselves. Sometimes even traces of two accumulations of plants and trees may be observed, the one separated from the other by clay, sand, or gravel. An observer should be careful to notice whether there are traces of such disturbance among the vegetable remains of the forest as to lead to the supposition that there had been a rush of water over them, or whether the same remains are so disposed as to leave little doubt that the causes, whatever they have been, which have produced the effects observed, have acted in a more tranquil manner.

XVI. *Raised beaches.*—We have above noticed that lines of coast have been raised by earthquakes: they may be also raised in a slow tranquil manner by some general and long-continued elevation of land

on the large scale. Lines of beaches are observed on some coasts raised above any waves which could now produce them, and in countries where volcanic action is not apparent.

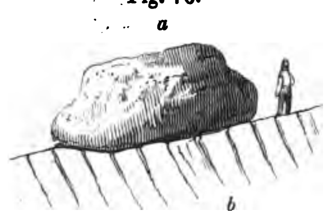
a. As lines of beach, thus elevated above the present level of the sea, may be of various ages, geologically speaking, though probably none are of any very remote antiquity, when considered in the same manner, it is especially necessary that the observer should carefully search for traces of organic exuviæ among the pebbles or sands of which they are composed. Even fractured shells, when all trace of character is not obliterated, should be preserved. If the beach occur on a coast where the molluscs and other inhabitants of the neighbouring sea be little known, as many of these should be collected as time may allow, for the purpose of comparison with those found in the raised beach. Indeed, the latter is sometimes composed of little else than fractured shells.

b. When an observer discovers a raised beach, he should compare it with that now existing on the coast, in order that he may see how far they resemble or differ from each other. If they resemble each other in the kind of pebbles, sands, contained organic exuviæ, &c., the general conditions of the coast have been the same at the respective periods of the production of both. If they differ, the general conditions have not been the same; and, consequently, according to the amount and kind of difference will be the inferences which may be deduced from the phenomena observed.

XVII. *Erratic blocks and gravel.*—Erratic blocks are large portions of rock which are found at various distances, sometimes considerable, at others small, from the masses of which they evidently once constituted a part. Erratic gravel is formed of smaller portions of rocks also transported to variable distances. For the theoretical conclusions which have been deduced from phenomena of this kind, we must refer the reader to geological treatises; we merely desire to direct the attention of the observer to a careful examination of any facts, relating to this subject, which he may have an opportunity of examining.

a. As many loose blocks of rock rise above the surface of land, such as pieces of granite, which are merely portions of the rock beneath them that have resisted the effects of decomposition better than it, the observer should be certain that the subjacent rock is different from any block, supposed erratic, which he may have before him. If *a* (Fig. 76) be a block of granite, and

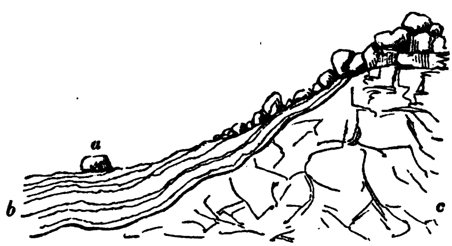
Fig. 76.



b a series of limestone beds, then he will be certain that *a* forms no part of the subjacent rock *b*, and *may* be erratic. He should next carefully ascertain that the block has not descended by the united effects of decom-

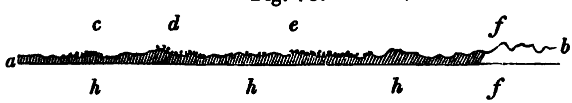
position, gravity and rains, as *a* (Fig. 77) has from a neighbouring height *d*, composed of large blocks of the subja-

Fig. 77.



cent rock *c*; so that the block *a*, though it rests upon a rock differing from it, *b*, is not erratic, in the sense the term is usually employed by geologists. If, however, he finds, as in the annexed section (Fig. 78), where, for the

Fig. 78.



sake of illustration, *a b* represents a horizontal distance of twenty miles, blocks of granite resting in various situations, *c, d, e,* upon rocks, *h, h, h,* which are not granitic, there being no doubt that they could not be derived in the manner above noticed, then an observer has erratic blocks, properly so called, before him. In the above section (Fig. 78), we have supposed similar granite to that of which the erratic blocks *c, d, e,* are composed to occur in place at *f*; so that it may be concluded that the erratic blocks were derived from *f*, and now occupy their relative positions from some transporting cause.

b. We have above considered the erratic blocks to be formed of granite. It must not, however, be supposed that an erratic block is necessarily composed of that rock. Any block of rock, no matter what the composition of it may be, if it occur on another different from itself, and has not fallen from a neighbouring height by the mere effects of unequal decomposition, gravity, and rain, is an erratic block. It is obviously of importance that an observer should correctly note the composition of any erratic block, so that he may be enabled to trace it to the mass of which it once constituted a portion. When blocks of various kinds are mingled in a heap before him, he should carefully estimate the relative proportion of each kind, so that, in tracing them to their sources, he may duly appreciate the direction and amount of the forces which have thrown them into one heap.

c. As it is difficult to conceive any other power than that of moving water to have transported erratic blocks into the positions where we now find them, we should expect, if they were hurried onwards in a body, and violently thrown against each other, that they would be rounded in proportion to the respective distances they have travelled. If they have been merely ice-borne upon floating and detached portions of glaciers, they may evidently have been carried considerable distances without exhibiting any other marks of friction than those which they may have experienced when falling originally on a glacier, or when brought to rest. Observations, therefore, on the angular or rounded characters of erratic blocks are essential, as also on their volume and weight; so that, when we come to calcu-

late the forces required to transport them, we may have good data for so doing. To ascertain the approximative volume or size of a block, an observer must evidently take some care, allowing for inequalities and any portion embedded in the soil. To obtain its weight, he must detach specimens which afford an average of the general structure, and ascertain the specific gravity of his specimens; after which the weight is readily calculated, the volume of the block being known.*

d. It having been found that the erratic blocks scattered on each side of the Alps diminish in volume and become more rounded as they recede from the central chain whence they were derived, an observer, if he discover erratic blocks on either side of a mountain-chain in any other part of the world, should direct his attention to this circumstance. As, in the Alps, ranges of erratic blocks are sometimes observable in a line some height above the bottom of a principal valley, through which they have evidently descended, this circumstance also should not be neglected. If the annexed sketch (Fig. 79) represent a principal Alpine valley, then a line of erratic blocks sometimes occurs as at *a*, while accumulations are occasionally found behind an elevation which is open to the line of valley, such as *b*, and where we may consider that an eddy would be produced if a considerable volume of water suddenly descended the valley. An observer should also direct his attention

* Suppose an observer finds the specific gravity of the rock to be 2·66; then as a cubic inch of distilled water weighs 252·458 grains, 252·458+2·66=671·5383 grains, the weight of a cubic inch of the rock. Having ascertained the weight of a cubic inch of any rock, that of any number of cubic feet can of course be readily obtained.

to any face of a mountain which may arrest the progress of such a volume of water in its passage down the valley, and see whether erratic blocks are there collected; and if so, whether they occur mixed pell-mell of all sizes, down to mere gravel.

Fig. 79.

e. Over extensive tracts of comparatively level country where erratic blocks occur, an observer should endeavour to trace the lines which the various kinds of rocks may have travelled. He can in some manner accomplish this by adopting particular colours for the different rocks, and marking on a map, by such colours, the lines on which he discovers such rocks. If the courses of that multitude of erratic blocks which occurs in Northern Europe and America were thus traced, even approximatively, much valuable information would be obtained. If this were done, we should find many colours

running short distances up to the parent rocks whence the blocks were derived, while others would extend across considerable areas. Some lines, though often curved in the small scale, would take given directions on the large; while many smaller lines would follow various directions.

f. It is important to note the relative age of the rock upon which erratic blocks rest, if the observer be sufficiently versed in geology: if not, he should carefully detach specimens from it—ascertain whether it contains organic remains or not: if it does, he should collect as many of them as he can; mark whether the beds, should the rock be stratified, are horizontal or not; and, above all, he should examine whether there are any evidences of the block having been encased in sands, marl, or clay, which having been removed by surface causes, has left the block exposed. It is considered that the blocks generally are superficial, and have not been covered by any body of transported matter, constituting a bed covering a large area, and to which some name, marking a particular geological epoch, has been assigned. It is therefore particularly necessary to pay attention to this point.

g. The observations on erratic gravel should be much the same as on erratic blocks. Great care should be taken to examine the kind of pebbles of which any mass of gravel covering an extensive district may be composed. It is obviously important duly to appreciate the causes which have produced their transport: whether they have been gradually detached from their parent rocks, and slowly transported by the aid of rivers or other aqueous agents, now daily in force, or

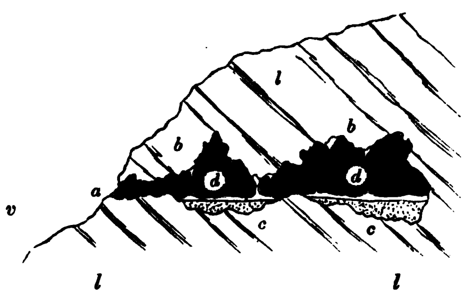
whether we must look to any more general action of moving water passing in greater volume over the land. When accumulations of gravel are only composed of pebbles that may have been carried down the valley in or at the termination of which they are found, the size, shape, and weight of the pebbles should be taken into account, and a fair estimate made of the power of the waters, now descending the valley, to carry them down, proper allowance being made for the slope of the river-channel, and the accumulative power of floods during a succession of ages. It should also be seen whether pebble-beds are, such as the celebrated Crau district (France), mere terminations of a great wash of erratic blocks. In some situations, gravels of different kinds rest upon each other; one having been formed by the action of rivers, another probably from the passage of a larger body of water:—this should receive careful attention. Again, though gravel-beds may appear superficial at one place, they may be only lower portions of a series of rocks, which can be traced beneath many others in another; a conglomerate bed having been weathered, the cementing matter removed and the pebbles left. It is necessary, therefore, that the observer pay attention to this circumstance.

XVIII. *Ossiferous caverns and osseous breccia.*—Ossiferous caverns are caves so named because in them the remains of various animals, such as bears, hyenas, elephants, &c. are detected, often enveloped by mud or other deposits, and in such cases concealed from ordinary observation. Osseous breccias are for the most part clefts of rocks, such as have been previously noticed (p. 110), filled with bones, fragments of rocks,

and an earthy or compact cement. They are sometimes connected with ossiferous caverns.

a. An observer after entering a cavern may again return from it without the slightest suspicion that it is ossiferous, and yet the cave contain the abundant remains of animals. Many in our own country, which have furnished hundreds of bones and teeth of various mammiferous creatures to those who properly searched for them, have been visited from time immemorial by numbers who never observed a trace of such exuviæ. Caverns are far more abundant in limestone rocks than in others; and hence the frequent occurrence of stalactital and stalagmitical matter in ossiferous caves, which often masks the organic riches contained beneath it. The conditions of ossiferous caverns vary; but the annexed section (Fig. 80) may serve to illustrate one

Fig. 80.



kind by no means relatively uncommon. Let *l l l* be a section of a limestone hill, in which there is a cavern, *b b*, communicating with a valley, *v*, by the entrance *a*. Let *d d* be a floor of stalagmite (a deposition of calca-

reous matter formed by droppings of water, containing carbonate of lime, from the roof), covering cavities, *c c*, in which there is an accumulation up to the stalagmite, *d d*, of the remains of animals, intermingled with mud, silt, sands, or gravel, as the case may be. It will be evident that an observer may pass in and out of such a cavern, treading on the stalagmite floor, *d d*, without being aware that the remains of animals are concealed beneath.

b. In some ossiferous caverns there has been a deposition of stalagmitic matter upon the bottom of the cave before any mud was introduced into it, and bones are often found sticking in the former: in fact, the latter have been covered over by the stalagmite as it formed. In other caverns, the mud, sand, or gravel of the bottom in which the bones occur is uncovered by stalagmite of any kind. In this respect there is considerable variation, as must happen from differences of local conditions, and of the manner in which the bones were introduced into the cavern.

c. When an observer discovers bones in a cavern, he should pay particular attention to their mode of occurrence. Let him make a complete section of the stalagmite, mud, silt, sands, or gravel, as the case may be, noting the depth of each different bed, and carefully abstract specimens from each before fragments of it become mingled with the others. He must be careful to mark whether different kinds of bones or teeth occur in particular beds, or are all mingled together. He should also make different sections of the cave at various points, particularly noting where or in what directions it may communicate with the surface; for caverns fre-

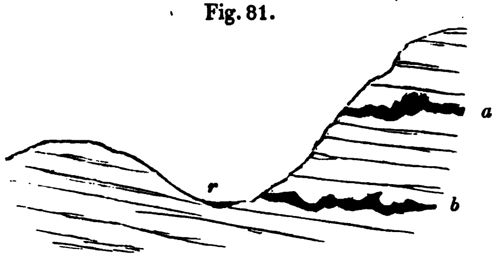
quently lead to the surface in other places than their entrances, such places being filled with fallen rubbish. It is particularly important to remark whether such communications are vertical or nearly vertical, so that they may have been open fissures before they were stopped up with the fallen rubbish.

d. An observer should be particularly careful in ascertaining the general external conditions of the situation where the cavern occurs; noting whether it was ever probable that it was concealed by gravel or angular fragments of rock, which having been subsequently removed by natural or artificial causes, a free entrance into the cavern was obtained. The celebrated Kirkdale cavern, which drew so much public interest to this subject, and which Professor Buckland showed to have been the den of an extinct species of hyena, that dragged into it the remains of extinct elephants, rhinoceroses, hippopotami, and other creatures, then inhabitants of Yorkshire, was closed by a covering of gravel, and was accidentally laid open by quarrying. If a cavern has remained open to the surface during long periods up to the present time, it may have been tenanted first by creatures now extinct, and subsequently by those now existing; and hence their various remains may be detected in it, sometimes mixed, at others in beds above each other. Consequently, the remains of man and his works may be discovered in such places, as has been the case, particularly in the South of France.

e. To ascertain whence any mud, silt, sand, or gravel may be derived which is mixed with the bones, or occurs in beds above or beneath them, an observer must study the position of the caves, as regards the physical struc-

ture of the neighbouring country. Let, for the sake of illustration, the annexed woodcut (Fig. 81) represent

Fig. 81.

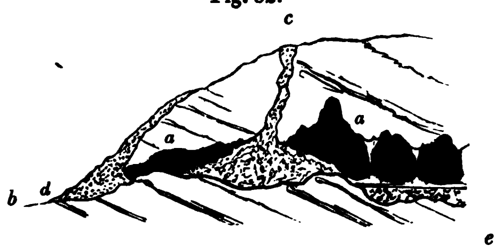


the section of a valley, on one side of which there are two ossiferous caverns, *a* and *b;* and let a river, *r*, running in the valley, be of sufficient size to bring down mud, sands, and gravel, according to the abundance of water in it;—it will be obvious that, from the position of the cavern *b*, such detrital matter might be carried during floods into it, and envelope or cover any bones lying in the places to which the water could find access: the waters might even surprise and drown living animals in the cavern. No such effects could be produced by the same cause in the cavern *a*. The observer will now see the importance of having collected specimens of the mud, sands, or gravel in ossiferous caverns: he can readily compare such substances with any alluvial matter brought down by a neighbouring river, and hence see any difference or resemblance between them. If pebbles be detected in these caverns, which could not have been derived by the actual rivers from the situations that could have furnished them, we must look to other causes for their presence in the caverns. And in this way, a variety of inferences may be drawn as to the

different circumstances which have attended the preservation of the bones of animals in different ossiferous caverns.

f. We have remarked, that observations respecting any vertical or nearly vertical communication of an ossiferous cavern with the surface is important. It is so, because we may then have a large accumulation of the bones of creatures which have fallen over the edges of the fissure while open. Let the annexed woodcut (Fig. 82) represent the section of part of a hill, in which there is a cavern, *a a*, communicating with the

Fig. 82.

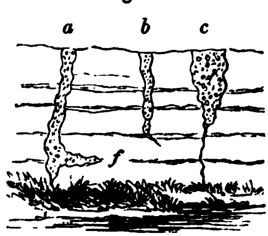


side of the hill at *b*, and with its summit by a fissure, *c*. This may have been a den of hyenas in the first instance; and the creatures which fell down the fissure *c*, would be consumed by them, leaving part of their bones; so that there might be an accumulation of bones of the hyenas and of their prey in the inmost recesses of the cavern *e*. We can readily imagine that, from the decomposition of the rock forming the hill, detrital rubbish could eventually so accumulate at the entrance of the cave as to close it at *d*, so that it was no longer tenanted by its old inhabitants; or supposing these able to keep the entrance open, when the time came for their

extinction, that it became closed, leaving the perpendicular fissure open. Now, if animals still continued to fall through the latter into the cavity beneath, there would be an accumulation of their remains, the bones which the hyenas formerly consumed remaining, injured only from the fall of the animals. Thus there may be two accumulations of animal exuviæ in the same cave, one having been effected under different circumstances from the other, the species even of the creatures which fell through the fissure being perhaps different; and yet to a careless observer the whole might appear one mass of mixed bones, fragments of rock and earth, introduced into the cavern through a lateral aperture; the perpendicular fissure having been gradually filled with fragments of rock, earth, and perhaps some animal remains. We merely notice such possible combinations of conditions to show the reader the necessity of correct observation, particularly when the bones of man are found mingled with the bones of animals under equivocal circumstances.

g. The transition of such a cavern as that last noticed into a cleft filled with osseous breccia is slight. Let the annexed sketch (Fig. 83) represent the face of

Fig. 83.



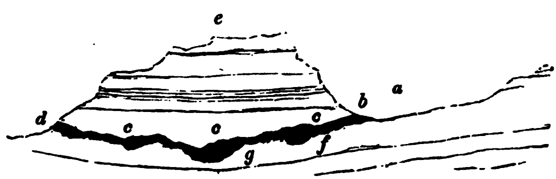
a natural or artificial cliff, exhibiting clefts, *a*, *b*, *c*, filled with a mixture of bones, earthy matter more or less indurated, and fragments of the adjoining rocks. It will readily be seen that they are in the condition of the open fissure *c* (Fig. 82). Sometimes there is a little offset from the main fissure, as at *f* (Fig. 83), —a kind of minor lateral cave. Having previously noticed more modern fissures of this kind (p. 110), we now merely call attention to the red calcareous cement so commonly detected in them, and which varies in its state of induration from an earthy to a very compact substance. From this circumstance, as M. de Cristol has observed, it has been too hastily concluded that all osseous breccias are of the same age, though they probably differ materially in this respect. The same author suggests,* that the red cement is but the red earth arising from the decomposition of the limestone in clefts of which the osseous breccia is found; and observes, that in all cases where the red cement occurs, the cleft is in limestone, or where matter may be washed from limestone. As far as our personal observations extend on the osseous breccias of Italy and Southern France, this opinion perfectly accords with facts. This red substance is considered to be washed by rains into the clefts and upon the bones; which latter continue to accumulate, and are thus eventually cemented together by the red substance, that becomes compact when carbonate of lime is introduced by aqueous infiltration among its particles.

h. There is another cause which may produce a mix-

* "Observations Générales sur les Brèches Osseuses:" Montpellier, 1834.

ture of the bones of various animals with fragments of rock, earth, and even pebbles derived from a distance, which an observer should bear in mind while examining an ossiferous cavern and the country around it. In some limestone countries, small rivers lose themselves in cavities, and, after running through a series of subterranean caverns, reappear on the surface at various distances from the spot where they first entered the subterraneous passage: it will follow, that they sweep into such caverns a great variety of organic and inorganic substances; and that the passage being sometimes closed by their accumulation, and the waters discharging themselves in other directions, such caverns, when explored, might be ossiferous, and rounded pebbles be mixed with the bones. Let the annexed diagram (Fig. 84) represent the section of a portion of country,

Fig. 84.



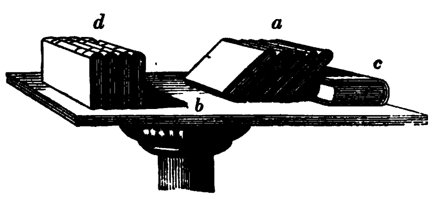
in which there is a depression, *a*, the lowest part of an area, which would become a lake if the waters did not find a subterranean passage beneath the hill or mountain, *e*, from *b* on the one side to *d* on the other, by the series of caverns *c c c*. It will be obvious, that the inorganic and organic substances, washed into the aperture *b*, will be first lodged in the depression *f*, and subsequently in the depression *g*. For the sake of illustra-

tion, we have made the series of caverns rise from *g* to the discharging aperture *d*. In such a case, the constantly accumulating remains of animals, pebbles, sand, and earth, mixed with fragments of rock forming the hill, would probably stop up the passage between *f* and *d*, so that either the waters would form a lake at *a*, or find some other passage for themselves. The reader can readily imagine a variety of modifying circumstances; such as a change in the physical features of the country before or after the aperture became closed, mixtures of bones and rocks produced by other causes, and the like.

XIX. *Dip and strike of strata.*—Before we enter upon directions for observing rocks of an older date than those now forming, it will be necessary to call attention to the dip and strike of those which are divided into strata or beds.

a. The dip is the angle which the plane of the strata or beds makes with the horizon. To illustrate this, let the annexed sketch (Fig. 85) represent a table, *b*, on

Fig. 85.



which some books, *a*, are made to rest in a slanting position by the support of another book, *c*, laid flat on

the table. If now we consider the top of the table to represent a horizontal plane, and the books beds of rock, then the angle which the sides of the tilted books *a*, makes with the table, *b*, would be called their dip, and according to the amount of the angle would be the amount of dip: that is, the less the sides of the books sloped, the less the dip; and, conversely, the more upright they were, the greater the dip. The book resting flat upon the table would be said to be horizontal, and have no dip at all. Let *d* be books standing upon the table with their backs upwards; then strata or beds of rock which occur in a similar position would be termed perpendicular or vertical.

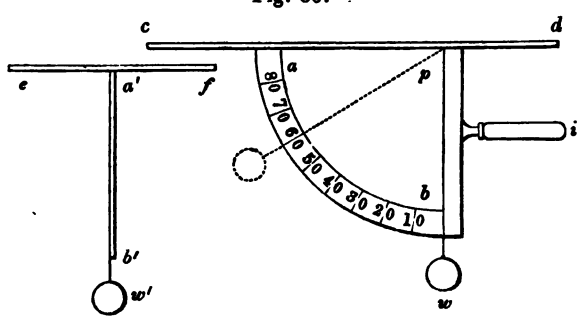
b. The strike or direction of beds or strata is a line at right angles with their dip. The lines which the backs of the books *a* and *d* (Fig. 85) would take towards the north, south, or other points, as the case may be, would be termed their strike or direction. Let us suppose that the books *a* dip to the west, then the lines of their backs would run north and south, which would be termed their strike or direction. Let us further suppose that the backs of the books *d* are arranged parallel to those of the books *a*; then the strike or direction of any beds of rock, situated as *d* and *a* are, would be the same, notwithstanding the beds at *d* would be vertical, while those at *a* would have a dip.

c. If strata or beds were always as regularly arranged with regard to each other as the books above noticed, or that the thickness of a bed were always as uniform as that of any given book, observations on the dip and strike of strata would be comparatively easy. It would be merely necessary to contrive some instrument

which should rest upon the face of a bed, and which should, by the aid of levels or a plumb line, show the angle that such face made with the horizon, to obtain the true dip; while a compass should show the point to which the bed dips, and would consequently give its strike or direction at right angles to it. Accordingly, instruments of this kind, named clinometers, have been contrived, and much ingenuity has been exhibited in their construction; but, in practice, there is not one situation in a hundred where they will be found to afford the least assistance.

Beds of rock, taken generally, afford surfaces which, viewed on the small scale, are rough and uneven, while on the large they may be considered to constitute planes that, when compared with the horizon, are either horizontal, dip at some angle, or are vertical. It hence becomes necessary to employ some instrument which is not placed on the uneven surface of a bed, but which, when held in the hand, or placed on some convenient stand, should afford the requisite information, at least in a fair approximative manner;—one, in fact,

Fig. 86.



which, by massing small irregularities, should afford a general plane that can be compared with that of the horizon. For this purpose we have found an instrument, represented in the annexed sketch (Fig. 86), extremely useful in practice. It consists of a graduated quadrant, *a b*, of platinum, silver, or brass, fitted in its upper part into a rectangular plate of metal, *c d*, having a polished upper surface, the proportion of the length to the breadth being as *c d* to *e f*. The quadrant is connected at *b* by a strip of metal fixed perpendicularly to the under surface of the plate *c d*; and from this portion projects a small ivory or ebony handle, *i*. It will be evident, if from this instrument we suspend a metal weight, *w*, by a fine hair, or other convenient substance, from the point *p*, which is the centre of a circle of which *a b* is a quadrant, and the instrument be so adjusted that when properly held by the handle *i*, the hair and weight, *w*, shall just graze the instrument, while the former cuts the zero of graduation, that the plane *c d* will be parallel to that of the horizon. Hence, if looking along the plane on the top of the instrument we find it coincide with that of a bed of rock under examination, we learn that the latter is horizontal, — at least the observation would be sufficiently correct for ordinary geological purposes.*

Let an observer have before him a range of beds or strata, that are evidently neither horizontal nor perpendicular, the dip of which he is desirous to ascertain; by inclining the plate *c d*, so that its plane shall coincide with the general plane of the rocks before him,

* *a′*, *b′*, *w′*, show the quadrant *a b*, and the weight *w*, as seen from behind, the handle of the instrument being removed.

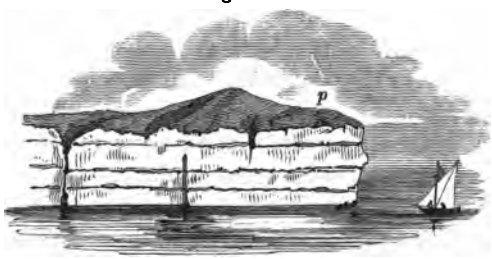
and allowing the hair, with the weight *w* attached, just to graze the graduated quadrant *a b*, the line of hair will cut the graduation at some point. The difference in degrees between this point and the zero of graduation will give him the dip of the beds of rock, or the angle which they make with the horizontal plane. If it be required that the surface of the plate *c d* should be so inclined that the hair, when held perpendicularly strained by the weight *w*, cut the graduation at 60°, then the dip of the rock would be 60° in some direction which remains to be ascertained.

Now, if the instrument has been properly held in the plane of dip, the direction of the longest sides of the upper plate will coincide with that of the dip. It remains, therefore, carefully to find this direction by a good pocket-compass, making proper allowance for variation from the true north; and the observer has the amount and direction of the dip required, and hence the strike or direction of the same beds. A little practice will soon render an observer sufficiently expert with this or any other instrument contrived upon similar principles. We should particularly insist on the necessity of making such observations with reference to the true, not the magnetic, north, in consequence of the errors that may arise from the shifting character of the latter.

d. In the foregoing observations we have supposed that the beds to be examined were so exposed, naturally or artificially, that an observer could readily obtain a true general view of their planes of stratification. This, however, is far from being always the case. It often happens, as for instance in the face of cliffs, that the

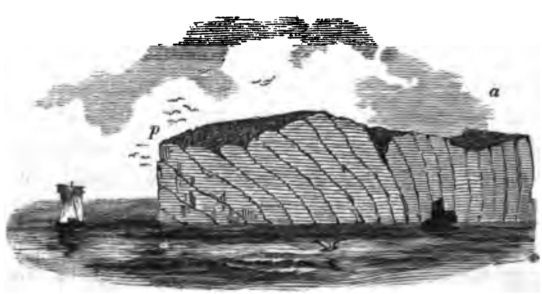
sections of beds offer mere lines. It will be obvious that these lines, viewed only in one sectional surface, may afford an incorrect idea of the true position of the beds. Let the annexed sketch (Fig. 87) be a view

Fig. 87.



of a headland from the south, in which some beds of rock appear to be arranged horizontally. Should an observer, in such a case as this, be unable to see the surfaces or planes of the beds, he should hesitate in considering the beds in question as really horizontal: he should endeavour to obtain some sectional view in another direction. Let us suppose, for the sake of illustration, that the headland noticed above trends away

Fig. 88.



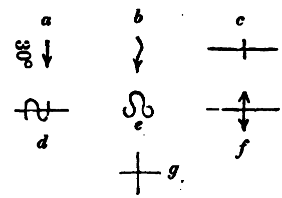
at the point *p* to the northward, affording the cliff-section annexed (Fig. 88), which is exposed to the eastward. In this instance the horizontal appearance of the beds when viewed from the southward is evidently deceptive, for the lines on the eastern side of the headland show a dip at a considerable angle to the north, and such lines, by a gradual curvature of the strata, finally exhibit a vertical character at *a* (Fig. 88).

e. When cliffs are under examination, the observer should always endeavour, if in a boat or vessel, to land, or at least to approach so near to the coast as to obtain a correct view of the general surface of the beds, which are not unfrequently exposed in such situations. Indeed there are few situations so proper for obtaining the dip and direction of beds correctly as coasts, particularly when washed by tidal seas. Large masses of rock rising through the sea, and which are exposed to the fury of the breakers during gales of wind, are particularly favourable for such observations. The above remarks are equally applicable to the apparent lines of stratification exhibited in inaccessible cliffs among mountains, where it is alike necessary to have more than one sectional view of the beds before we can even judge approximatively of their dip.

f. When the dip of a rock, and consequently its strike or direction, are correctly ascertained, an observer should instantly note it; for if many dips be taken in a short time, and they vary either in direction or in the amount of angle, the chances are that he will commit some error when he commits them to paper at the end of his day's work. We should also strongly advise that they be entered upon a map, if there be one of the lo-

cality or district examined, at the time of observation; for by so doing accuracy is ensured, and the observer, as he advances in his work, gradually perceives the stratification of the country unfolding itself before him by mere reference to his map. We have found the following signs (Fig. 89) extremely useful for the purpose

Fig. 89.

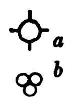


of reference. The arrow, expressing the dip and pointing to its direction, has long been in use: *a* shows the direction of the dip, the head of the arrow pointing to it. If the bottom of this page represent the south part of a map, then the dip of a rock marked by *a* would be to the south. The angle at which a rock dips can be conveniently marked on the side of the arrow: thus *a* would be the dip of a rock to the south at an angle of 30°.—*b* shows that while the strata undulate on the small scale, they dip as a mass in the direction of the point of the arrow *b*; *c* represents perpendicular strata, the longest line showing the strike of the beds; *d* exhibits strata which, while they are contorted in such a manner as to show no given dip, have still a marked strike, represented by the straight line; *e* shows strata which are so contorted that complete confusion is exhibited, and therefore neither dip nor strike can be repre-

sented; *f* is a sign for an anticlinal line, or one from which strata dip on either side;—(the ridge of a house-top will convey an idea of an anticlinal line, the slopes of the roof representing the dip of the beds on either side;)—*g* is a cross formed by the intersection of two equal straight lines, and is a sign for horizontal strata.

g. It has often been supposed that the division of rocks into beds is characteristic of those deposited from water, in which the matter composing them was either in chemical solution or mechanically suspended. This, however, is not strictly true, inasmuch as tabular masses of basalt, trachyte, and their respective conglomerates, do cover each other over areas of various magnitudes: hence the above-noticed signs should be equally applied to any rock that is divided into beds, whether they be considered of aqueous or igneous origin. The object sought by means of these signs is simply to mark upon paper that the rocks of given localities, if they be divided into beds, either dip in a particular direction, have a certain strike, are contorted, or the like, without reference to their supposed origin. In general, however, rocks of an igneous origin occur in masses. To show this on geological maps, though it has not, we believe, yet been done, is evidently useful. For this purpose we should recommend the annexed signs (Fig. 90), in which *a* represents the occurrence of a rock in mass. Igneous rocks are sometimes also columnar; indeed this structure is sufficiently common in some, such as basalt; this character can be represented by the sign *b* (Fig. 90).

Fig. 90.



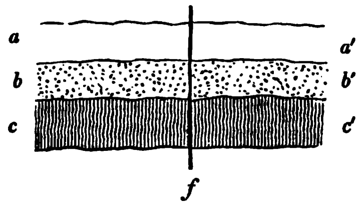
XX. *Faults and contorted strata.*—There are few things which require more constant attention on the part of a geological observer, than the errors into which he may inadvertently fall from inattention to those dislocations of strata, technically termed *faults*, which so frequently occur. Attention also to contortions is equally necessary. From the amount of contortion we may in some measure infer the intensity of the force required to produce it; and from the kind of rocks so bent and twisted, we may ultimately learn the conditions necessary for such contortions.

a. It has been by no means an unfrequent practice, in constructing geological maps, to ascertain the strike of a series of rocks, and then cross the country in lines at right angles to this strike, such lines being occasionally at a considerable distance from each other. We have found this plan particularly liable to error, lines of dislocation or faults being thus wholly overlooked. It is necessary that a geologist should cover the country, if we may use the expression, with a net-work of observations, to ensure accuracy, not only in this, but in other points.

b. It will be obvious that faults will be apparent in proportion to the general stratification or character of the rocks in which they occur. It will be very difficult to ascertain, by mere surface inspection in the interior of a country, that a rock, stratified vertically, has sustained any perpendicular movement of elevation or depression, or that a rock in horizontal stratification has sustained any horizontal movement: for in both instances similar rocks will adjoin similar, and hence the dislocation be difficult of detection. Let the annexed

sketch (Fig. 91) represent a map of a portion of

Fig. 91.

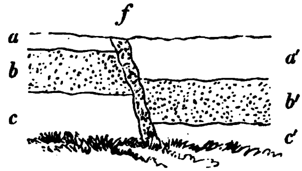


country composed of three rocks, *a*, *b*, *c*, the beds of which are vertical; it will be obvious that if they be traversed by a fault *f*, which lets down the beds perpendicularly, *a'*, *b'*, *c'*, on the one side, will abut against *a*, *b*, *c*, on the other, and therefore the presence of the fault be unnoticed. If the sketch (Fig. 91) be now considered as a section instead of a map, it will be equally clear that a horizontal movement will always bring like beds against each other. Under such circumstances, an observer will often find lines of considerable springs of use to him, since they frequently burst out in lines of fault. He should particularly direct his attention to patches of broken ground and cliffs in the suspected line of fault, and there search for marks of dislocation.

c. Having ascertained the existence of a fault, which is often sufficiently apparent in sea-cliffs, or in situations where rocks of different mineralogical characters come suddenly in contact, an observer should endeavour to ascertain whether the sides of the fault are in close contact or not. He should carefully search for any traces of friction which may have polished or marked with lines the surfaces of the sides, noting if the lines

seem to coincide with the supposed direction of the dislocation. When the sides of a fault do not absolutely touch, as in the annexed section (Fig. 92), he

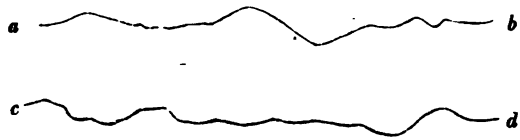
Fig. 92.



should examine the substances, commonly termed the contents of the fault, found between the surfaces of the fault. The contents of the fault *f* may be either derived from the rocks *a*, *b*, *c*, or from some other sources. If there has been much grinding of the sides of the fault before they ultimately settled in their present relative situations, the fragments may have been more or less crushed and pulverised. If the fault has gaped from the commencement, the fragments would fall from their own gravity, and therefore we should expect that fragments of the rock *c* would not be found above *b* (Fig. 92).

d. An observer should particularly attend to the direction of a fault, taking its general bearing as respects the true north, east, west, or south, as the case may be; and while he carefully notes the deviations from its principal line of direction, he should endeavour to trace the range of the fault as far as possible, in order to ascertain what should be considered its true line of bearing. Let *a b* (Fig. 93) represent the range of a fault for twenty miles, and let the top and bottom of the page correspond respectively with the north and south parts

Fig. 93.



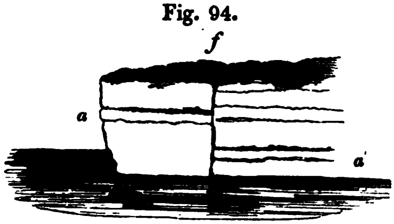
of a map; then the range of the fault *a b* will be east and west, notwithstanding its subordinate deviations from that direction. It will be obvious that, if two or three miles only of the fault be traced at parts intermediate between the points *a* and *b*, the fault might be considered to have other directions. Hence the necessity of tracing faults to comparatively considerable distances when practicable.

When many faults occur in a district, it is always desirable to ascertain how far they may be parallel to each other. In such cases, as in the direction of any one fault, the general range should be attended to, instead of the directions of minor parts. Let *c d* (Fig. 93) represent a fault, also about twenty miles long, occurring in the same district with the fault *a b*; then these two faults may be considered parallel to each other, notwithstanding there is scarcely two or three miles of any given portion of each which are strictly parallel. It will be obvious, that in laying such faults down on maps, the scale of the latter may either be so large as to show numerous subordinate directions, or so small as almost to convert them into nearly straight lines. We have, for the sake of illustration, supposed the faults to be about twenty miles in length. Now, if we imagine the fault to range to a far greater distance, it may so happen that the direction attributed to this line of fault may not be the true one, upon the same principle that

several minor portions of *a b* and *c d* would not give their true directions. When faults are traced only for about a mile in length, it will frequently require much hesitation on the part of the observer before he states that the range of the whole fault is in any given direction. If the line of fault be laid down on a map for the distance observed, no error can arise, since such line, if correct, will merely represent a matter of fact, and others will be enabled to judge of the inferences which may be deduced from it; but when words only are employed, the case is different. If only told that a fault has a given range, without being informed that the same fault has been only traced for a short distance, we may be misled, since the direction given may not be that of the fault when traced through greater distances.

e. The observer has strictly to attend to the amount of vertical dislocation in a fault; that is, the distance to which the broken and once continuous rocks have been forced from each other vertically. To obtain this amount of dislocation correctly, requires care, — more, perhaps, than is often taken. If the beds be horizontal, as in the annexed section (Fig. 94), and the fracture *f* be verti-

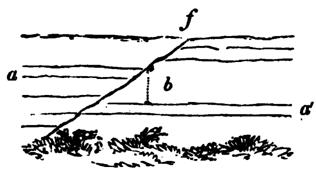
Fig. 94.



cal, then the distance of the marked bed *a* on the one

side from a' on the other, measured perpendicularly, will give the amount of dislocation. If, however, the fracture be not vertical, but slanting, while the beds themselves retain their horizontality, as in the annexed section (Fig. 95), in which the same letters represent

Fig. 95.



the same things as in the previous section (Fig. 94), then the distance measured down the line of fracture would not give the amount of dislocation, as will be seen by comparing the two sections (Figs. 94, 95) together, for we have purposely represented the amount of vertical dislocation equal in both. To ascertain the amount of dislocation, it will be necessary to drop a perpendicular line, *b*, from the end of the upper part of the dislocated bed, where it abuts against the fault, and the distance from the dislocated portions of the bed so measured will be the distance required.

f. The observer will readily perceive that strata may occur, relatively to fractures and faults, in such a manner that to obtain a correct estimate of the amount of dislocation in such cases will require much attention. We must leave him to exercise his own skill and ingenuity in obtaining the object sought in such cases; for it would be occupying too much space to advance hints for the various complicated arrangements of fractures and beds which may occur.

g. We may here call the attention of the observer to those larger dislocations of rocks which constitute mountain masses, and which, having been squeezed up against each other more in certain directions than in others, have given rise to the lines of elevated land commonly termed ranges or chains of mountains. Such dislocations are but faults on a larger scale than those so frequently seen in more level countries. The masses broken are larger, the lines of fracture longer, and the amount of vertical dislocation more considerable. They are, however, mere cracks on the earth's surface; and their relative importance will be better understood by the observer, if he take a common artificial globe in his hands, measure the comparative length of a chain of mountains upon it, and estimate its height as compared with the diameter of such a globe, than if he listen only to those descriptions, which, however beautiful they may be, are still but deceptive, since they lead us from a true estimate of the relative importance of mountains as regards the earth's surface generally. If an observer be so embarrassed among mountain scenery that he measures all around him by his own relative magnitude, and loses a general view of the cracks and disjointed masses of rock, regarded only as such, in the imaginary magnitude of surrounding objects, he is not likely to advance this portion of our subject. Let us not be thought to underrate the value of mountain scenery. We should be ungrateful if we did so; since our happiest moments have been passed amid glaciers, torrents, and ravines, our feelings excited and our thoughts occupied by little else than the scenes around us. An observer may readily be both geologist and

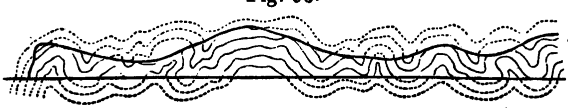
artist; but when he views nature as the former, he must, for the time at least, place the artist aside, and consider mountains as mere dislocated masses of rock, thrown up in lines, and forming relatively minute ridges and depressions on the superficies of our globe.

h. The directions given for observing the smaller dislocations of rocks will apply also to the larger: the means for obtaining the measurements of the distances which any mass may be moved on either side of a great fault will necessarily be more complicated than those employed for observing a small fault. Having noted the dips, if any, of the rocks, the amount of vertical dislocation seen on the sides of mountains, or on the two sides of a valley, must be obtained trigonometrically, or by aid of the barometer. The horizontal amount of movement must be sought trigonometrically in the usual manner. As the lines of fracture or fault in mountain chains are important in determining the value which should be attributed to given directions of fracture, prevailing at given epochs of their elevation, great care should be taken to determine this point; the observer duly considering that general lines of direction are sought, and hence that minor and subordinate directions of a great line of fracture should not be confounded with them, as has been noticed above in the case of smaller faults.

i. When an observer finds himself among contorted strata, he should endeavour to see whether the beds, notwithstanding their contortions, have a given strike, as is often the case. Let the lines of this page represent the strike of the beds; then the reader will have no difficulty in considering that the paper, supposed to

represent some given bed, can be plaited and crumpled in such a manner that the lines of print can be made to form the tops or bottoms of contortions having a given direction or strike, the ridges of the contortions being parallel to each other. If now, when a piece of paper is plaited or crumpled up in this manner, we, as it were, plane off a piece of the upper surface, we shall obtain a series of cut edges of paper all parallel, or nearly so, to each other. Let the annexed diagram (Fig. 96) represent the end view of several pieces of

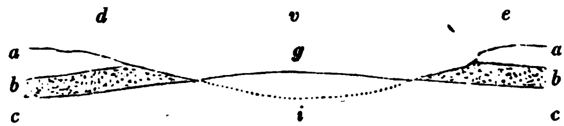
Fig. 96.



paper or cloth plaited or crumpled up in parallel ridges: if we now consider these pieces of crumpled paper or cloth to represent a series of rocks contorted in the same manner, that *a b* is the sea-level, and *c d* an outline of several hills, we should, in those parts of the figure which are not dotted, obtain a view which may be observed on several coasts, such, for instance, as that extending from Hartland Point (North Devon) to the southward.

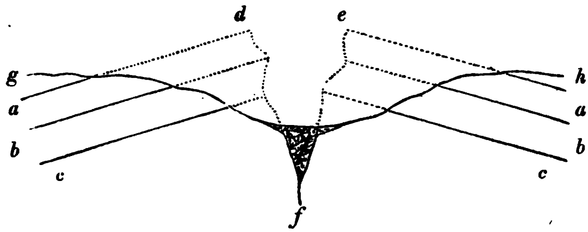
k. It will be obvious that, in a district of contorted strata, the general plain of dry land may so cut the contortions that there may be numerous bosses of inferior beds rising through superior; while the latter may be depressed in basin-shaped cavities of the former. If it should so happen that abrading surface-causes act upon beds raised upwards, in such a manner that they are worn away in a basin-shaped cavity, then the resulting depression is termed a circus, or circular valley of

Fig. 97.



elevation. Let the annexed sketch (Fig. 97) represent a section of a protrusion of beds, from contortions or flexure of the strata, by which *a*, *b*, *c*, are raised upwards at *g*; and that *c* is a rock which has better resisted surface abrasion than *a* and *b*; then the depression *v* would be termed a circus of elevation, if the escarpments *d* and *e* formed a kind of circular or oval range of high land around the depression *v*, with probably some outlet for the general drainage of the waters, flowing into or falling upon the depression. We have supposed, for the sake of illustration, that the rock *c* had resisted surface abrading action sufficiently to rise upwards, in a kind of minor hill, in the central part of the depression, because this not unfrequently happens in such cases. The same figure may be made to illustrate valleys of elevation, by taking the dotted line *i* for the bottom of the valley; so that *d* and *e* are hills on either side. In this latter case, we suppose the rock *c* to have been abraded and worn down to *i*. It will be necessary for the observer to ascertain, whether the valley is not a crack or fissure so upheaved as to produce the outward dip from the central line of valley, or a mere abraded contortion, such as is given Fig. 97. Let the annexed section (Fig. 98) represent a fissure in which the rocks *a*, *b*, *c*, have been upheaved, so that when first broken the fractured beds formed the gaping cavity *d*, *f*, *e*. If now the fractured rocks be so worn down that the line *g h*

Fig. 98.



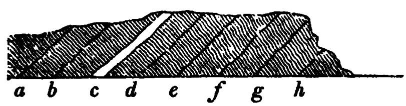
represents the actual surface of the country, the lines of the beds might seem to give simple curves, broken into by the abrasion of the land generally. The observer will therefore direct his attention to the central parts of the valley, and note whether the rocks be continuous across, or if such parts be filled with gravel, or other detritus, to such depths as would render it probable that the lower part of a fissure has been filled by it. By noting carefully the amount of dip on either side of the valley, and then by constructing a *proportional* section of the whole valley—one in which the heights and distances are on the same scale,—he will also be enabled to judge how far either a great flexure or fracture of the rocks may afford the most probable explanation of the phenomena observed.

XXI. *Cleavage or joints of rocks.*—Rocks, both massive and divided into beds, usually termed strata, are sometimes split in lines which are exceedingly deceptive, inasmuch as they may be readily confounded by the inexperienced observer with those of beds. In fact, many errors have arisen from inattention to these divisional planes. As the terms 'cleavage' and 'joints,' as applied to the structure of rocks, have been used with distinct theoretical meanings, we shall here, for

convenience, employ the term 'structural planes' for those planes which are not planes of stratification. We do so, not from any objection to the words 'cleavage' or 'joints' in themselves, but to avoid the theoretical application of these terms, in the present state of the inquiry, in the observation of mere facts.

a. Structural planes on the small scale may frequently be noticed among argillaceous slates. Let the annexed diagram (Fig. 99) represent the section of a cliff composed, with the exception of the bed *c*, of argillaceous

Fig. 99.



slate, and let the observer find two kinds of lines; *a*, *b*, *d*, *e*, *f*, *g*, *h*, being those of planes which dip in one direction, while the laminæ of slate take another, as represented by the short lines in the figure. He may probably be embarrassed regarding the planes, which should be considered structural; for he must by no means consider that the laminæ are always such, and that the planes of the larger masses are those of the beds or strata; since we have seen instances, in slate countries, where the laminæ of the slate appeared to be in the true planes of the beds, while the lines forming larger masses were those of structural planes. Where difficulties of this kind occur, the observer should carefully search for some interstratified bed of sandstone or other marked rock which shall give him the true direction of the beds. In the above diagram (Fig. 99) we have supposed such a bed to exist at *c*, which would show that the lines *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, were those of stratification, and the

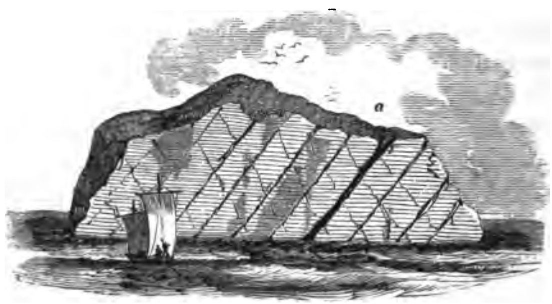
lines of the laminæ those of structural planes. We have seen slate rocks split in three directions by different planes, so that it required great caution in discovering which were structural, in the sense here understood. Among other places, this fact is readily observed near Morte Point on the north coast of Devonshire. One series of planes dips northward, another southward, and a third series traverses the others perpendicularly in north and south directions. Fortunately, some hard beds, at no great distance, afford the true dip and direction of the strata; but, as this does not always happen, we must particularly caution the observer to be on his guard as to the dip and strike of beds in districts of argillaceous slates, particularly when extensive natural or artificial sections cannot be obtained.

b. It sometimes happens, that the structural planes traverse equally argillaceous slates and sandstone, or other hard beds associated with them. In the grauwacke group, this may not unfrequently be seen. In these cases the structural planes are more frequently perpendicular to the general stratification than otherwise. When they are not so, the observer can scarcely confound the structural lines with those of stratification; since he will, by taking the lines which mark those of similar substances,—such, for instance, as sandstones,—readily ascertain the latter. He might, however, when the structural lines are perpendicular to the dip of the beds, mistake them for those of faults. In such cases, it will be necessary for him to see whether there be any dislocation, or merely lines which cut in given directions downwards without deranging the relative position of the beds.

c. Cross divisional planes in limestones of the dark-

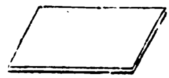
coloured and compact kinds, such as those of the carboniferous and grauwacke groups of England, are by no means unfrequent, and require the observer's attention, since the mineralogical character of numerous superimposed beds is often the same; so that when there is a want of organic remains, it is no easy matter to decide upon which are the true lines of stratification. Let the annexed sketch (Fig. 100) represent an isolated rock

Fig. 100.



of limestone standing in the sea, and let two series of parallel lines cross each other as there represented. The observer should, in such a case, search for some trace of a thin interstratified shale-bed which may afford him the true lines of dip and strike. We have, for the sake of illustration, supposed such a bed to exist at *a*. When such cannot be detected, he must endeavour to ascertain whether there is any appearance of a bed, differing from the rest, taking one direction more than another;

Fig. 101.



and he should especially seek for organic remains, since separate beds often contain marked accumulations of them.

d. Among some compact sandstone rocks, particularly those of the age of the grauwacke group, beds will be found divided into rhomboidal prisms and other solids of the like kinds, such as that represented above (Fig. 101). The observer should see how far they generally resemble each other in the same beds, and how far their forms may differ according to their mineralogical structure. As the study of these rhomboidal or prismatic bodies has as yet received little attention, it is desirable that collections be formed of them, for the purpose of inquiring into the causes of their production.

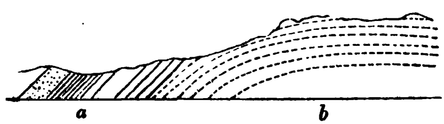
e. Structural planes are by no means confined to those rocks which are divided into beds and have been deposited through the agency of water. Rocks which would be otherwise massive, and which are referred to an igneous origin, are also divided by such planes. In granite this is a very common circumstance, and portions of that rock often appear as if artificially arranged from this cause. The structural planes of granite are

Fig. 102.

generally such, that the mass is divided into numerous short prisms with a rectangular base. These, when exposed to the action of the atmosphere, or that of the sea on coasts, frequently present the appearance of some huge ruin. The blocks are generally, as in the annexed sketch (Fig. 102), so piled upon each other as to form tall prisms, composed of several others having an equal base.

f. An observer should carefully direct his attention, in the structural planes of protruded granite, to the influence which, by giving a particular form to the mass, an adjoining surface of pre-existing rock has apparently exercised upon the lines. Let the annexed section (Fig. 103) represent the junction of protruded granite,

Fig. 103.

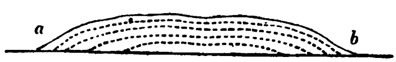


b, with the pre-existing stratified rock, *a*, which there is sufficient evidence to show has been tilted up by the former: then the observer should note how far the lowest surface of the rock *a* has influenced the upper structural lines of the granite *b*. We have often seen, that in such cases one set of structural lines takes the direction of the dotted lines in *b*, causing the granite near its junction with the stratified rocks to appear, at first sight, like beds dipping in the same direction as the latter. Clearly to perceive that these are not true beds, the observer should search for perpendicular planes, cutting directly down through the apparent beds. He will often find two sets of perpendicular

planes crossing at right angles; so that the mass of granite is divided into numerous blocks, which sometimes rise in masses, forming those picturesque summits known by the name of Tors in the district of Dartmoor in Devonshire.

g. When granite and some other igneous rocks rise through a country in the shape of great bosses, it will be frequently observed that there is the same tendency of one set of structural lines to correspond with the external form of the boss; and that these are again cut by other sets of structural lines, which cross each other nearly at right angles, and cut through the first set. Let the annexed diagram (Fig. 104) represent a sec-

Fig. 104.



tion of a boss of such igneous rock; then the observer should see how far one set of structural lines corresponds with the external surface, as is, for the sake of illustration, supposed to be the case between the surface line *a b*, and the internal dotted lines.

h. At the junction of igneous rocks generally with those among which they have been protruded, an observer should carefully search for any traces of structural planes in the former. It most frequently happens that such cannot be found; but as we have sometimes seen igneous rocks, such as certain porphyries and greenstones, split into parallel planes, so as to give them a schistose structure, we would recommend more attention to this point than it has hitherto received.

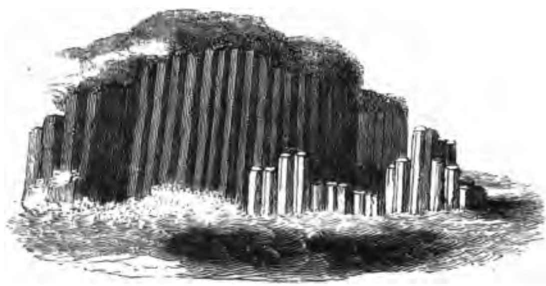
i. In all cases of structural planes, whether in the stratified or unstratified rocks, the observer should pay particular attention to the direction or strike of the lines, more especially to those which are perpendicular, or nearly so. They have been observed in some countries to take given directions very constantly over considerable areas, even across several rocks. These directions should be taken with reference to the true, not the magnetic north.

k. Certain igneous rocks are divided into a multitude of prisms, and are thence termed columnar. Whether or not this kind of division should strictly be considered under the head of structural planes, in the sense here understood, we shall not stop to inquire, but proceed, for the sake of convenience, to notice it here. The Giants' Causeway and the Isle of Staffa are well known examples of the columnar structure of basalt in the British Islands. In both these instances, the mass of basalt consists of beds, which appear to have been spread successively over each other in a melted state, particular circumstances having at times prevailed which rendered them columnar. When the columnar structure is developed, the observer should note whether the columns be jointed, as in the annexed sketch (Fig. 105), or simply continuous from the top to the bottom of the mass,

Fig. 105.

as in the annexed view (Fig. 106). When the columns are of great size, they should be measured. Some at

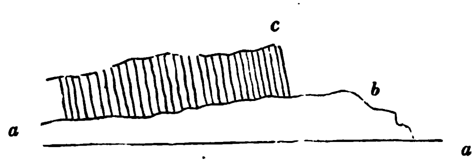
Fig. 106.



Fairhead, on the north-east coast of Ireland, were thus found to be 317 feet in height. The number of sides of which the prisms are composed should be noted, as also whether the prisms are very variable in that respect, or mostly hexagonal.

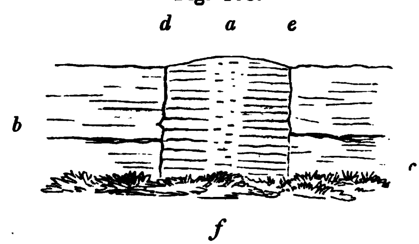
l. In all cases where a rock with this columnar structure is seen to repose upon another rock, the observer should see if the columns rise at right angles to the plane of the rock upon which they repose. Let, in the annexed sketch (Fig. 107), *a b* represent the section of

Fig. 107.



a plane of rock upon which a mass of columnar rock reposes; then it should be seen if the columns of *c* are, or are not, at right angles to the line *a b*. With regard also to the columnar structure sometimes observable in the igneous rocks forming dykes (see p. 30), it should be observed whether or not the columns extend perpendicularly from the walls of the dyke to the central parts. Let *a* (Fig. 108) be a dyke of igneous rock in-

Fig. 108.



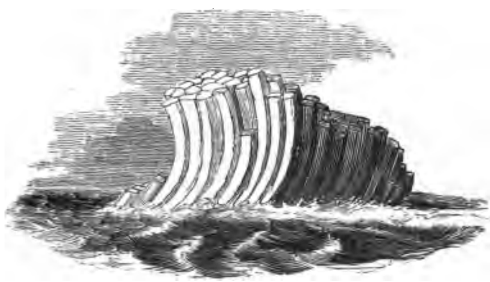
terposed between the once continuous beds *b c*; then it should be seen if the columns extend perpendicularly from the walls or sides of the dyke *d* and *e*, as we have here represented them; and if so, whether there is a certain amount of confusion in the central portion of the dyke *a f*, as in the figure, or whether the columns actually traverse from side to side.

m. The igneous rocks in which the columnar structure is developed are very various, comprehending some lava currents, basalts, trachyte, pitchstones, greenstones, numerous porphyries, and others of the like kind. The observer therefore must not suppose that because a rock is columnar it is necessarily basaltic, as is somewhat the opinion of those unacquainted with geology. This structure does not even prove that the rock exhibiting

it is of igneous origin, since it has been observed that beds of aqueous production, such as sandstones, are occasionally columnar beneath, or adjoining to, masses of igneous rock; and it is inferred that this arises from the long-continued heat to which the aqueous rock has been subjected before the igneous matter finally cooled, since similar effects can be produced artificially.*

n. The columns are not always straight. They are sometimes curved, as in the annexed sketch (Fig. 109).

Fig. 109.



It would be very desirable in such cases to observe, if possible, what modifying circumstances have produced this deviation from the more common arrangement; whether it depends upon an irregularity of the surface on which the columnar rock rests, or on something in the latter itself.

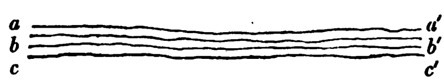
XXII. *Fossiliferous rocks, or those which as a mass contain organic remains.*—Having previously (p. 8) shown that every bed comprised within this class does not necessarily contain organic remains, and

* See Quarterly Journal of Science, 1829; and Geological Manual, pp. 471, 472.

noticed (p, 13) the names which have been given to the various groups of which it is composed, in the order of their relative antiquity and superposition, we now proceed to the manner of observing them. The chief objects sought are their relative order of superposition, the manner in which they have been formed, and the nature of their respective organic contents.

a. Direct observations on the actual superposition of any series or groups of beds are necessarily those of the first importance, since whatever value is to be attributed to mineralogical structure or organic contents, as characteristic of contemporaneous deposits over areas of greater or less extent, the importance of these supposed characteristics must depend upon observations which show the actual continuity of the deposits themselves. Let the annexed woodcut (Fig. 110) repre-

Fig. 110.



sent a section in which three groups of beds can be traced continuously from *a b c* on the one side to *a′ b′ c′* on the other; it will be obvious that if they can be demonstrated to be three continuous and distinct masses of matter, they may differ entirely both in mineralogical structure and organic contents at *a b c* and *a′ b′ c′*, and yet be of contemporaneous origin respectively, geologically considered. Mineralogical structure and organic remains, be their value what it may, must be subordinate to actual superposition.

b. If rocks were bared of all vegetable and other covering, so that an observer could actually walk upon a series or group of beds from one part of a country to another, or, extending the area, traverse several countries, he would constantly see beneath him any changes, whether of mineralogical structure or of organic character, which might take place in any series or group of rocks that he might be tracing. As he cannot do this, he must look to natural or artificial exposures of rocks for such information on this head as he can obtain. These he finds on sea-coasts, on the banks of rivers, among mountains, in ravines of various kinds, in mines, in roads and lanes, in lines of canals, &c. It will be obvious that an observer must set out from some place in which the series or group of beds he intends to trace has a certain mineralogical structure, and, in the case of the rocks under consideration, contains certain remains of animals or vegetables, as the case may be. The student of geology may here very properly inquire how he is to know when he is on any particular series or group of rocks, if a contemporaneous deposit may possess a different mineralogical structure at one place and at another, and may even differ in its organic contents; though respecting the latter character it is but fair to state, that numerous geologists so confide in it that they take it as a guide in preference to all others, even considering it as conclusive evidence. We would advise the observer in Europe to adopt those various groups into which, after considerable labour, geologists now divide the fossiliferous deposits of this part of the world. Many, no doubt, are very artificial; but they are extremely convenient, at all events, in the present state of

science. In other parts of the world, where as yet geological researches have not been so extended, we would strongly urge geological observers to examine countries with reference to the structure of such countries respectively, and not employ those names alone which have been given to particular groups in Europe. It will be evident that given groups of the fossiliferous rocks may eventually be traced through various modifications from Europe into Asia and Africa; but when any such rocks are at once assumed, without intermediate points of comparison, to be the same in distant places—such, for instance, as India—with the minor divisions of European deposits, we are evidently in danger of committing most serious errors.

c. Respecting a considerable part of Europe, particularly its western portions, an observer will find so much valuable information in various geological maps, treatises, memoirs, and local works, that there are not many situations in which he could not obtain some information as to the supposed general structure of any locality he may be desirous of examining; and as far as our geological experience extends, now nearly over twenty years, he will find the more advanced geologists ever ready to assist him in his labours. Still he should proceed to examine the relative superposition of the rocks in any district he may wish to explore, in order to convince himself that the opinions advanced on such subjects are correct; and he can do this even without knowing to what particular groups the rocks before him may be eventually referred. Instructions on this head will obviously also apply to those countries where rocks,

from the want of sufficiently extended researches, have not yet been arranged in groups.

d. Let us suppose that an observer has a range of

Fig. 111.

cliffs before him, such as is represented above (Fig. 111), and that he commences his labours with the lowest visible rock, *a*; he will note its mineralogical structure, that is, he will see whether it be a marl, sandstone, limestone, or the like. Let us suppose that *a* is a limestone composed of numerous beds. The observer should now search for organic remains in them, which, for the sake of illustration, we will consider that he finds, and that he carefully distinguishes the fossils obtained from each bed by marks which prevent error in this respect. Let us further suppose that *b* is a siliceous sandstone, which we thus divide from the limestone *a*, because all analogy would teach us that the causes productive of a siliceous sandstone must differ from those which formed a limestone. He will now search for organic remains in the siliceous sandstone *b*; and thus he will proceed with the respective rocks *c*, *d*, *e*, *f*, which we suppose to differ mineralogically from, and clearly to rest upon, each other; the observer having satisfied himself, by proper researches, that all chances of error under this head have been carefully avoided.

By proceeding in this manner, he obtains a certain series of deposits which he provisionally assumes to be

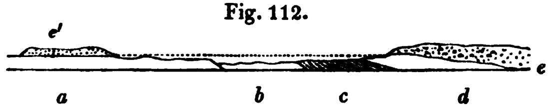
distinct. He may now either search for other deposits occurring above or beneath this series, or he may trace its continuity horizontally through the district. In the latter course, he necessarily sets out with a knowledge of the superposition of the rocks exhibited in the cliff section, and is therefore in a condition to appreciate any change which may take place, either in their mineralogical structure or organic contents, as he recedes from the situation where he first directly observed their relative superposition. If he has carefully attended to all the natural or artificial sources of information that present themselves, he will see whether any two rocks, which were fairly distinct in the cliff section first noticed, merge into a deposit that should be considered as one only,—or whether, on the other hand, another rock should gradually become developed between two others, so that it will be necessary to distinguish a deposit between some two of those noted in the first section, and of which no traces exist there.

For the sake of illustration, we have assumed that the cliff section (Fig. 111) was of the most simple kind, the rocks resting in a parallel manner; or, as it is termed, *conformably* upon each other. We cannot afford space for notices of the variable manner in which rocks may rest upon each other. However this may be, the principle on which to conduct the inquiry remains the same. The first object sought is direct evidence, if it can be procured, of the relative superposition of the various rocks observed.

e. It may be necessary to notice briefly that kind of superposition which is termed an *overlap*, since it is one which may lead to erroneous conclusions. Let the

annexed diagram (Fig. 112) represent the section of a country several miles in length, and let an observer be

Fig. 112.

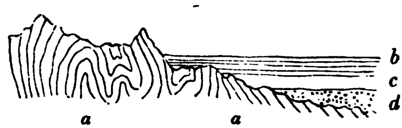


so placed as to have the left-hand portion under examination. He there sees that the rock *e′* reposes upon *a*. This he notes in the manner directed, and due care is paid to their mineralogical structure and organic contents respectively. He might now conclude that in the series of rocks generally *e′* succeeded *a*. Let us now suppose that the observer is desirous of extending his researches towards the right hand, and that he proceeds in that direction until he encounters the rock *b*; upon examining which he becomes startled by finding that it is not the same, either in mineral or organic character, as the rock *e′*, and yet that both succeed *b* in the order of superposition upwards. He might be tempted to believe that *b* was the continuation of *e′*, notwithstanding the differences above noticed. In this he would evidently be wrong, as *e′* is an overlap, being the continuation of *e* on the right hand,—a rock which comes, in the order of succession, after *d*, which is itself separated from *a* by *b* and *c*. In such cases as these, *e* and *e′* once formed continuous portions of the same rock that has been thus separated by the action of denuding surface-causes, which have not only destroyed the continuity of *e*, *e′*, but also cut somewhat into the beds beneath. It will be obvious that any newer deposit may overlap or rest upon an older; and that

numerous intermediate deposits, which would complete the series in any given part of the world, may be wanting, as it is termed, between them.

f. Groups of rock, though composed of beds that differ mineralogically from each other, such as marls, sandstones, conglomerates, and limestones, which overlap other groups, should be duly noticed, more particularly when the appearance of the inferior beds justifies us in concluding that they have been subjected to the action of a disturbing power before the superior rocks were formed. Let *a a* in the annexed section (Fig. 113)

Fig. 113.

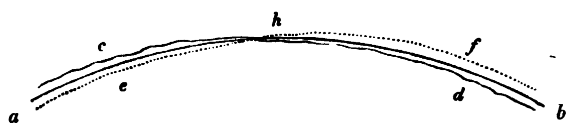


represent some given rock, such, for instance, as a mixture of dark-coloured limestones and argillaceous slates, partially covered by a red conglomerate, *d*, a light-coloured limestone, *c*, and a gray marl, *b*; then there will be no difficulty in perceiving that *a a* was disturbed and contorted before *b*, *c*, *d* were deposited; and, consequently, that *d* may not be the next rock to *a* in the series, viewed generally, since, in those situations to which the disturbing force did not extend, tranquil deposits may have been effected between the production of *a* and *d* respectively. In the section before us (Fig. 113) the observer would have evidence that the group of rocks *b*, *c*, *d*, was quietly deposited upon the upturned and contorted strata *a a*, and that therefore they

do not form component parts of the same group, at least in this locality. By proceeding in this manner, without absolutely depending either on mineralogical structure or organic character, though these are highly necessary aids, various groups of beds may be established in extensive districts, which, as masses of matter, have been formed successively and independently of each other.

g. An observer should bear in mind that a particular portion of the earth's surface may have been so situated relatively to another, that traces of a series of deposits effected in one place can only be very differently, if at all, represented in another. It will be difficult to represent this by a diagram in so small a space as this page; but perhaps the annexed sketch (Fig. 114) may to a certain extent assist the reader. Let the arc *a b*

Fig. 114.



represent a section of the sea-level over part of our planet, let *c d* be the solid surface of the earth, which rises above the sea-level at *e*, constituting dry land, while it plunges beneath that level at *d* and forms the bottom of the sea: it will be clear that numerous marine deposits may be effected upon *d*, while a comparatively small amount of lacustrine or fluviatile deposits may be thrown down on *c*. In fact, after a certain time the latter may be hardly appreciable, while the former continue as abundant as ever. Compare, for example, the

amount of deposits which may now be forming on the surface of the British Islands with that which may be taking place in the seas around them. Let a geological change be effected in the part of the earth's solid surface represented above (Fig. 114), so that the dotted line *e f* represents its position relatively to the sea-level *a b*, which, for the sake of illustration, we have supposed to remain much the same;—*e* will now form the bottom of the sea, and *f* will constitute dry land; *e* therefore will now be the surface on which marine deposits are effected, and *f* will receive the terrestrial. To render our illustration simple, we have been compelled to suppose these changes in the relative positions of sea and land to have been so effected that the point *h* always formed a coast. Such a condition of the point *h*, it may hardly be necessary to remark, would be in the highest degree improbable. We can do no more, in this confined space, than endeavour to illustrate the principle sketched above: there will be no difficulty on the part of the observer in imagining numerous modifications of it. Under such conditions, the probabilities would be, that the greatest differences would be observed at the greatest distances, *a* and *b*, while the least would be found at the intermediate point *h*.

h. We now proceed to note the mode of observing the mineralogical structure of the fossiliferous rocks, not because we consider this structure more important than their organic character,—that is, the general character of the organic remains found in them,—but because inorganic mineral matter constitutes their mass. Viewing this matter generally, and from its present condition, we infer that it has either been mechanically or chemi-

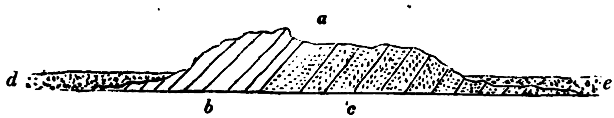
cally deposited; that is, has either been pushed forward by moving water, thrown down from moving or still water in which it was mechanically suspended, or has been chemically separated from sea or fresh water in which it was, for the time, held in solution.

i. When an observer finds a *conglomerate*, that is, a number of rounded pebbles cemented together by some substance, such as a sandstone, limestone, clay, or the like, his first object should be to ascertain the nature of the pebbles. He will carefully see if they consist of rocks known in the neighbourhood: older than the conglomerate they must of necessity be, otherwise they could not be included in it. He will then, if the pebbles be of different kinds, estimate the relative proportions of each. He will now be in a condition to judge of the relative distances they may have been moved to their present situations, and also of the direction whence they may have travelled.—We must here caution the observer against a circumstance which sometimes happens. A conglomerate may consist partly of pebbles derived from a more ancient conglomerate, and partly of rounded fragments of more simple rocks, such as sandstones, limestones, and the like. In such cases it would be right to learn the composition of the more ancient conglomerate before the observer proceeds to judge whence certain pebbles have been derived.—Another circumstance should also receive attention. It occasionally happens that rounded fragments are discovered in a conglomerate which cannot be traced to any known rock, either at the neighbourhood or at considerable distances. We have noticed this fact in conglomerates (of the red sandstone series) which were

mixed with trappean rocks, produced probably in a manner not very different from the lavas of a modern volcano. In such cases we may either consider that these pebbles have been ejected from a volcanic crater, as often happens at the present day, or form parts of masses of trappean or other rocks concealed beneath the conglomerate.

k. The term *breccia* is applied to the angular fragments of rocks which are cemented together by limestone, clay, sandstone, or the like. From this form of the fragments we infer that they have not been exposed to much friction, and, consequently, have not travelled far. We necessarily expect to find little else than the fragments of those rocks on which the breccia immediately rests. Let *a* (Fig. 115) represent the section of

Fig. 115.



a ridge of pre-existing rocks, composed of a limestone, *b*, and a siliceous sandstone, *c*, and *d* and *e* breccias on either side: then, as a general fact, the observer would find the breccia *d* composed of fragments of the limestone *b*, while *e* was formed of fragments of the sandstone *c*, and yet *d* and *e* may have been contemporaneously formed; the causes which produced fragments of the respective rocks and their subsequent consolidation into breccia having acted simultaneously on both sides of the ridge *a*.

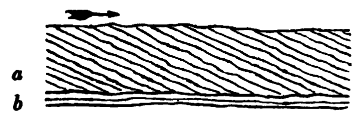
l. It sometimes happens that there is a mixture of

angular fragments of rocks and of rounded pebbles in the same bed. The observer should carefully note the nature both of the fragments and of the pebbles, distinguishing any difference between them, and their amount relatively to each other; remarking, in such cases, how far the mass may resemble an ancient shore, in which there was a mixture of angular fragments, semi-rounded and rounded pebbles, all of the same rock,—or whether the rounded pebbles have been derived from a distance, and the angular fragments from pre-existing rocks of the immediate vicinity. Alternations of conglomerates and breccias are occasionally found constituting one great mass of beds; as also a thick bed of conglomerate resting upon another of breccia, or the reverse. These facts and their attendant circumstances should be carefully noted.

m. The distinction between a fine-grained conglomerate and a coarse-grained sandstone is of necessity to a certain extent arbitrary, as they merely form intermediate and consecutive states of the comminution of matter by friction from large fragments to a fine powder. Perhaps, so long as the rounded grains show clearly that they have been derived from some known rock, the mass of which they are the principal component parts may be termed a conglomerate. When an observer discovers that a conglomerate bed gradually becomes finer grained, and finally passes into a sandstone, it is very desirable that he should note the conditions of the change. If the whole has been formed upon a pre-existing surface by a movement of water which pushed detritus over it, he may in many instances learn the direction whence the whole is derived, even

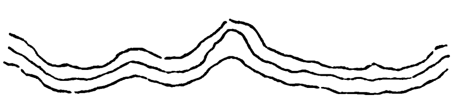
when the bed becomes a sandstone, by searching for diagonal lines, such as those represented in the annexed section (Fig. 116) in the bed *a*, which from analogy

Fig. 116.



we infer have been caused by the pushing process of moving water previously noticed (p. 71). By gently clearing away portions of the sandstone, the planes of which these diagonal lines are sections can often be obtained, and their dip and strike can be ascertained in the same manner as those of thick beds of strata (p. 190). Having done this, the observer obtains a general idea of the direction whence the sand forming the sandstone was derived, by considering it at right angles to the strike of the diagonal laminæ, and opposite to the direction of the dip; since such must have been the direction whence the particles of sand were pushed over the inclined plane towards the surface *b* (Fig. 116). We say a general idea, because we can scarcely suppose, that the gradually advancing line over which the particles of sand were pushed would be straight: it would, probably, be curved or composed

Fig. 117.

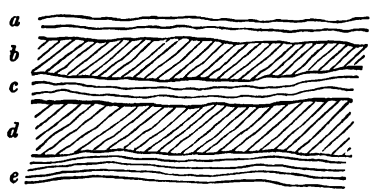


of numerous minor protrusions, when seen from above,

in the manner represented in the annexed horizontal plan (Fig. 117,) and therefore it would be necessary to obtain the general strike of the planes of laminæ in order to learn the direction of the pushing action of the moving water.

n. The observer will frequently find these minor lines of section in sandstones exceedingly various; and as much may be learned from them, correct drawings of those exhibited in natural or artificial sections are very desirable. Let us suppose that one of the following kind is thus obtained (Fig. 118;) then, commencing

Fig. 118.



with the lowest part, we may infer that *e* was a bed of sand, the particles of which were thrown down from water in which they were mechanically suspended; *d*, another bed formed by the pushing process; *c*, a precipitate from mechanical suspension; *b*, the result of the pushing process along the bottom; and *a*, a bed formed in the same manner as *c* and *e*. If the planes of the laminæ of *b* and *d* coincide generally, it may be further inferred that the direction whence the moving power acted was the same in both cases; in other words, that the current, or moving body of water, which by friction pushed the sands onwards along the bottom, took the same direction in both cases. The observer will some-

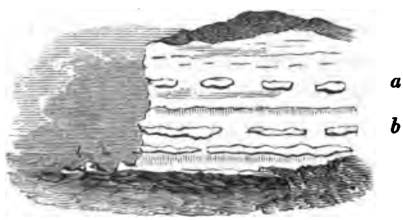
times find considerable confusion in the lines of laminæ with intermixtures of coarse and fine sand, and even of conglomerates, which may induce him to conclude that there has been much confusion in the directions and velocities of the currents of water, which have either pushed detrital matter onwards, or, from a diminished rate of movement, lost the power of sustaining it in its state of mechanical suspension.

o. As from all analogy we consider conglomerates and breccias to have once been loose rounded pebbles or fragments of rock, which have been subsequently formed into a compact mass by the cementing substance now found between them; and, in like manner, that sandstones were once incoherent sands, now consolidated; so do we infer that fossiliferous shales, fine-grained slates, marls, and clays, were once mud, which, according to its original composition, and the circumstances to which it has been subsequently exposed, has assumed the forms we now see. We should infer that the finer the matter mechanically suspended in water, the more extensive and uniform would be the deposit from it when circumstances permitted or caused its descent to the bottom from a moving mass of water; and hence that, in a series of such mechanical rocks as those now under consideration, the marls, clays, or slates, as the case may be, would be more uniform throughout horizontal distances than the sandstones, and these latter more uniform and extensive than the conglomerates. An observer should therefore carefully attend to this point, and narrowly search for circumstances which may have produced modifications of it.

p. It often happens that there are concretions and

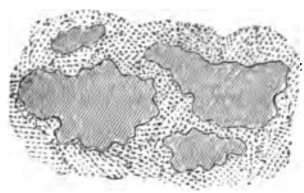
spherical or spheroidal nodules in sandstones and clays which are considerably harder than the rocks that include them. Let the observer note whether they occur in lines parallel to the general stratification, as is the case with those represented at *a* in the annexed section (Fig. 119), or irregularly dispersed through the

Fig. 119.



rock. Having obtained a nodule, let him examine if it be composed of concentric coats, or formed of laminæ parallel to the general stratification of the beds. He should also see if the matter of the nodules differs from that of the surrounding rock, noting whether or not there has been an aggregation of similar matter, such as carbonate of lime and the like, apparently separated from the mass of the rock after deposition. It often also happens that these indurated portions extend out in the shape of imperfect beds, as at *b*; so that when the including marl, clay, or sandstone, as the case may be, is removed from them, they constitute a series of irregular flattened masses arranged in the same plane, which, when viewed from above, have the appearance of the annexed plan (Fig. 120), where the shaded portions represent the flattened masses, and the dotted parts the including rock, both seen from above. These

Fig. 120.



and similar facts should be noted, since they lead to much curious theoretical inquiry.*

q. Intermixed with the above-noticed *mechanical rocks*, as they are often termed from their supposed origin, limestones of various kinds are more or less frequent. Some may be also perhaps termed mechanical, while the rest are inferred to have been formed by some chemical change in the water in which the carbonate of lime was held in solution, such as the loss of the disseminated carbonic acid which previously rendered it soluble, so that the matter of the limestone was deposited. The observer will direct his attention to the compactness and other characters of these limestones, noting their connexion with the rocks associated with them. Some siliceous sandstones so resemble certain limestones, that more care is necessary in distinguishing them than an inexperienced observer may at first sight suspect. It hence is extremely desirable that he should furnish himself with a small bottle of acid, (muriatic is that most commonly employed,) for the purpose of detecting the difference on the spot. Con-

* For further observations respecting the aggregation of similar matter in the mechanical rocks, see Researches in Theoretical Geology, p. 94—100.

venient bottles for containing the acid can readily be procured at the philosophical instrument maker's.

r. We cannot, in our limited space, detail the numerous modifications of mineral structure which can be observed in the above-noticed rocks, nor of the associations of the mechanical and chemical deposits in the fossiliferous series. Some modifications are considered characteristic, and are undoubtedly of considerable value when proper attention is paid to the relative areas over which they occur. Thus, the well-known rock called chalk forms a particular deposit from the north of France, through the British Islands, part of Germany, Poland, and European into Asiatic Russia. This form of carbonate of lime is not, however, confined to this particular deposit, neither does the latter always appear as chalk; so far from it, that deposits, considered to be contemporaneously produced with the white chalk above noticed, are formed of dark-coloured marble limestones, and even siliceous sandstones. Again, another group of rocks is, for convenience, termed oolitic, because some of the component beds in western Europe are formed of limestone, composed of little rounded and often concretionary grains, which resemble the roe of a fish. This structure is not confined to the group in question, but is found in others; neither do rocks contemporaneously produced with it necessarily show any traces of it.

s. For the various modifications of mineral structure found among the fossiliferous rocks, we must refer to treatises on geology: we can only here direct the attention of the observer to them generally, endeavouring to show, that if we desire to arrive at their causes, due

regard must be paid to the mode in which the various rocks, noticed above, occur relatively to each other, the changes of structure which take place in horizontal directions, and any other circumstances which may lead us to the object desired. Fearful of appearing to bias the opinion of the reader upon points which may as yet be considered unsettled, we abstain from pressing upon his attention one series of facts more than another: we must leave him to infer from his own observations whether the various fossiliferous rocks have been produced by the same kind of agents which are now daily in force on the surface of our planet, or whether greater intensities of similar or different agents may be considered more or less necessary partially, or in any manner, to explain the various phenomena observed.

t. We now arrive at the subject of organic remains, the relative importance of which must not be considered with reference to the space here allotted to it. From being once utterly neglected, it has become one that has excited the greatest interest. It has arisen into importance as the supposed exclusive value of mineralogical structure sunk; and as the latter, after receiving too much attention, is now in some danger of not receiving enough, the value of organic remains may perhaps, after having been neglected, be now somewhat overrated. Upon this subject, however, we must leave the observer to deduce his own conclusions, and refer him to nature for the best evidence he can procure upon it. We should advise him, if opportunities offer, to study the forms of the various genera of fossil shells, corals, plants, and other organic remains, which are collected in museums; obtaining, as much as possible, the aid

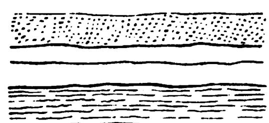
of competent persons to direct his researches, in order that his eye may become accustomed to such forms.

To acquire a knowledge of all the small differences which are supposed to characterise different species, requires very great application and comparison; in fact, it is a study, and a laborious study, of itself. The geologist who has devoted many years to his science may indeed gradually accumulate a great amount of knowledge on this head; but this being a work of time, those who have not laboured long at observation must content themselves with leaving the determination of species to experienced geologists, who have well studied this subject, or to those naturalists who have occupied themselves with zoological and botanical geology, either by itself, or as an extension of their more peculiar inquiries. We more particularly caution young observers on this head, because it is considered that certain species, more particularly of shells, characterise contemporaneous fossiliferous rocks for considerable distances,—and that hence, there being a general disposition in those who commence the study of a science to consider the received opinions of the day as all equally well founded, species, though something like when hastily viewed, may be stated to occur in situations where they are not found. We do not mean to enter upon the delicate question of the necessary distinctions between species and varieties; we merely call attention, for the purpose of avoiding error, to the importance of leaving such subjects to those who have devoted their time to them.

u. One of the first objects to which the observer should direct his attention is the mode in which organic

remains occur in rocks. If this be coupled with the mineral structure of the latter, he may obtain an insight into the manner in which the remains of animals and plants, now found fossil, have been entombed. In the first place, he should carefully note whether they present any marks of having been rolled or transported from greater or less distances,—or whether the plants, shells, corals, &c. preserve their forms so uninjured that it may be fairly inferred they have been enveloped by the matter of the rock in the relative situations where they now occur. Let us suppose that *a*, *b*, and *c* in the annexed section (Fig. 121) are a sandstone, a lime-

Fig. 121.



stone, and a marl respectively, and that each is fossiliferous, containing fossil shells; and further, that the latter are fractured and worn in the sandstone, beautifully preserved in the limestome, and compressed or crushed individually in the marl, though otherwise perfect in the latter. The observer may fairly infer that the organic remains in the sandstone are not found in the situation where the molluscs or conchifers, of which they are the exuviæ, once lived, while such may readily be the case with those in the limestone and marl. Another condition of the fossil shells is, we have supposed, to be compressed in the marl while they are uninjured in the limestone. This will readily be under-

stood to be the result of pressure exerted upon the marl by the weight of any rocks that may have been formed above it. From all analogy, we consider that as the limestone accumulated, it encased the shells in hard, solid matter, so that the whole formed one compact mass, and therefore the shells would not be compressed by the weight of any superincumbent rock. This, however, would not be the case with the shells in the marl, which we suppose, from analogy, to have been in the state of mud when the former were included in it, and hence, that when pressure was exerted upon the mud, the shells became crushed in their places.

It must not be inferred, from the illustration above given, that organic remains are necessarily worn and otherwise injured among sandstones, and well preserved in other rocks; for fossils are frequently perfect in the former. We are merely desirous of calling attention to the condition in which organic remains are discovered, and of showing that such condition should be considered with reference to the mineral structure of the rocks in which they are found.

v. It is always desirable to note those facts which may enable us to judge whether the animal and vegetable exuviæ discovered have been quietly entombed, or have been brought to rest by deposition from a rush of waters, in which animals or plants were tumultuously borne onwards with gravel, sand, or mud. As we cannot conceive that limestones have been produced otherwise than in a tranquil manner,—at least those which do not appear to have been aggregations of carbonate of lime from mud after deposition,—the observer is in no great danger of error if he considers the beds of

limestones to have been respectively produced on a bottom beneath water, and that any changes in the organic contents of the various beds arose from changes in the kinds of animals which existed on the bottom, and that these may have been occasionally mixed with animal and vegetable exuviæ drifted from a distance. When therefore he sees the section of a limestone bed with organic remains in it, he has before him a portion of the bottom of a former lake or sea, except in such cases where it may be inferred that the limestone bed has been produced by the gradual deposition of carbonate of lime, in successive incrustations, upon grass and other substances, from the evaporation of the water which contained it in solution, as is often seen upon land.

When an observer finds that organic remains are arranged in planes parallel to the general stratification of the including rock, as in the annexed sketch (Fig. 122), where the broken lines parallel to those of the

Fig. 122.

beds represent lines of marine organic remains, then the evidence would lead him to infer that he has before him a section of several distinct and successive bottoms of the sea, that the organic exuviæ in the beds have also been accumulated on these bottoms in succession, and that they have been tranquilly covered up, one accumulation after the other, in the order of their relative superposition. For the sake of further illustration, let us suppose that the cliff is composed of a calcareo-siliceous sandstone, *a;* a coarser grained siliceous sandstone, *b;* a marl or clay, *c;* and an argillo-siliceous sandstone, *d.* Then he would be enabled to infer that, as far as the evidence of the locality went, the bottom of the sea was at first a kind of silt; afterwards, mud; thirdly, coarse sand; and finally, a sand among which carbonate of lime was much disseminated. These would be the great changes of the bottom of the sea in which the whole mass before him was formed: the number of minor changes would be shown, if not entirely, at least to a great extent, by the number of the respective lines of organic remains visible in each bed.

It may be here noted, that in some rocks, such as marls and the like, where there seems to have been so constant an accumulation of fine detrital matter that the evidence of the successive bottoms of a sea or lake is exceedingly obscure, much assistance may sometimes be obtained by searching for lines of those singular fæcal remains, termed coprolites, for the knowledge of which we are indebted to the labours of Professor Buckland. It may readily happen that, in a bottom of mud, lines of organic remains would with difficulty be formed, some creatures burrowing in it to various depths, and the

hard remains of molluscs, fish, saurians, and the like, tending to sink also to variable depths, according to their relative specific gravities. The fæcal remains of fish or aquatic saurians may have been showered in great abundance upon such bottoms, covering them with a sheet of coprolitic matter, of which part indeed may, from greater specific gravity, have descended lower than the rest, but of which the whole, taken as a mass, would be spread over areas that would depend upon the amount of supply from above. An observer may have proof that such a state of things was not improbable, by searching for sections of the accumulations in question; though it must not be inferred that these fossils are not found singly, for such is a very common fact.

w. When an observer discovers organic remains thrown together in a confused manner, without parallelism to the stratification of the including beds, he can scarcely consider that they are the remains of animals or plants which lived upon the bottom of the sea or lake, as the case may have been, and were tranquilly covered up,—or that they were lightly drifted to, or descended gently down upon, a pre-existing bottom on that spot. He should in such cases endeavour to learn the point whence the mixture of organic and inorganic substances has been derived, by noting the mineralogical structure of the rock in the manner previously recommended.

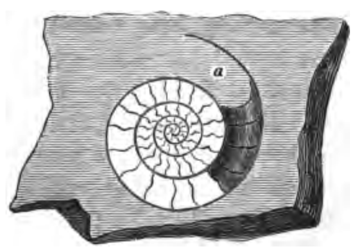
x. By comparing the forms of the various organic remains hitherto discovered with the animals and plants which at present exist, it has been inferred that they are the exuviæ of animals and vegetables which were, as now, terrestrial, fluviatile, lacustrine, or marine. With

regard to minor points of detail,—such as whether a particular species should, or should not, be considered marine or otherwise,—questions may occasionally be raised; but there seems no reason, from any existing evidence, to doubt the correctness of the inference generally. We must refer to treatises on geology for those views which have been hence formed respecting the conditions of different portions of the earth's surface at various geological epochs. Terrestrial animals and plants, when mixed with aquatic, may evidently have been so in two ways: they may either have been borne onwards together by the same mass of moving water, and have been deposited from it, as the latter, from sufficiently diminished velocity, lost its transporting power; or the terrestrial animals and vegetables may have been drifted, either violently or quietly, from dry land into water, beneath which both they and the aquatic organic remains were alike entombed in any deposit which might be subsequently formed. Having previously (p. 108) noticed the manner in which organic remains are entombed in deposits now forming, we merely now recall the attention of the observer to that subject, leaving him to judge how far the agents now in force will afford an adequate explanation of the various phenomena he may notice, and which are connected with this subject.

y. When an observer discovers a fossil shell, let him notice its position relatively to the stratification of the bed in which it occurs; for we may infer that the plane of the bed was often nearly that of the plane of the horizon when the bed was formed. If it be an univalve, there may be some difficulty in inferring that its animal was

either dead or alive when the shell became fixed in its present position: if, however, it be a bivalve, it is by no means probable that its animal was alive if the two valves were open and turned either up or down, the valves extending horizontally as regards the plane of the including bed. If the shell be of a chambered kind, an ammonite for instance, and of which the nautilus affords a familiar example, he should note whether it rests upon its side or occurs in other positions. With respect to fossil shells, it may be here noticed that some kind of evidence may be obtained as to whether the animal was in the shell, no matter whether dead or alive, when enveloped by the matter of the including rock, by paying attention to the extent to which the latter has penetrated. Let the annexed sketch (Fig. 123) represent a section of an ammonite in a portion of

Fig. 123.



rock, the first external chamber of the ammonite, *a*, being only partially filled with the matter of the rock, (let it be an argillaceous limestone, such as part of the deposit named lias,) so that there is a portion towards the interior of the shell which either remains a cavity, or is filled with crystallized carbonate of lime, or other

substances, which have percolated through the rock in a state of aqueous solution. In such a case, we may infer that there was an obstacle in the first chamber of the shell, when enveloped by the matter of the rock, which prevented the latter from filling the interior part of the cavity; and probably an observer would not err greatly if he further inferred that this obstacle was the fleshy body of the animal. He therefore might conclude that the ammonite in question was either enveloped by the matter of the rock while its animal was living, or before it had time to suffer decomposition.

If echinites (commonly termed sea-eggs or urchins) be the fossils found, the observer should remark if they occur with their mouths downwards, as they would do when at rest in a live state; and if they be of those kinds which are armed with large spines, it should be noted whether these are attached to the body of the echinite; for if so, then it would seem to show that the creature had been enveloped by the rock either alive, or before decomposition took place sufficiently to cause a separation of these large spines from the rest of the body. Much information may thus be obtained respecting the condition of encrinites, insects, fish, reptiles, and mammifers, prior to their envelopement by the matter of a rock, by noting whether their harder parts are relatively situated as they would be if still held together by the fleshy or softer portions. If, for example, an observer find a fossil saurian, as they have been found, with all their bones in their respective places, and in as good order as if in a prepared skeleton of a recent creature, it is fair to infer that it either was alive when first included in the matter of the rock, or

was so quickly enveloped by it that neither predacious creatures had displaced the bones, nor decomposition had caused them to fall into disorder. The perfect manner in which some organic remains are preserved is most remarkable; the minute scales covering the skin have been detected so completely in place in some specimens of those fossil saurians named ichthyosaurus, that they have the appearance of the skin itself. The contents of the intestines of fish and saurians have been noticed not only in the relative situation they occupied in the body, but also showing the form of the intestine in which they occurred previous to death. M. Agassiz states that the capsule of the bulb of the eye is preserved in many fossil fish.

While organic remains are thus sometimes as beautifully perfect as if prepared for the purposes of instruction by the comparative anatomist, others are widely scattered about, showing that they have either suffered decomposition, and that their harder parts have been thus separated from each other by moving water, or that they have been scattered by predacious creatures. Sometimes the bones of terrestrial mammifers are covered by fossil oysters, or the remains of other creatures of like habits: this would inform the observer, that the bones once lay without any fleshy covering upon the bottom of a sea or estuary, and that the oysters there attached themselves to them.

It would be out of place further to notice the inferences that may be deduced from the mode in which organic remains occur in rocks; the foregoing remarks will be sufficient to show the importance of correctly observing it. It may nevertheless be stated, that while

some fossil plants show they have been drifted, sometimes quietly, at others tumultuously, to their present positions, others pierce through several beds, or rise upwards in such a manner as to render it extremely probable that they were tranquilly enveloped in place by the matter of the rocks which now enclose them.

z. We should here offer some suggestions respecting the manner of obtaining specimens both of rocks and of organic remains. To obtain a knowledge of the true structure of a rock, unaltered by the action of the atmosphere upon it, specimens should be obtained from situations where no decomposition from this cause has been produced. In some rocks these situations are near the exposed surface; while in others it is only at some distance beneath such surface, and by means of quarries, or other artificial excavations, that they can be attained. The observer, bearing this in mind, will therefore endeavour to procure specimens illustrative of the true character of rocks in those localities where he will best attain the object sought. It is also desirable to obtain specimens which may illustrate the amount of decomposition of certain rocks from atmospheric causes: these will necessarily be found near or on the surface. The specimens should advantageously display the structure of the rock, and their size will depend upon the facilities which the observer may possess of transporting them. In all cases they should be sufficiently large to afford the information required from them. When obtained, the specimens should be carefully wrapped in paper, the locality having been written on a strip of paper and enclosed with the specimen; or a particular mark may be made on the specimen, or enclosed

strip of paper, which shall correspond with a similar mark in the observer's field-book, in which remarks, generally, accompanied when practicable by sections, should be carefully entered.

When an observer has an organic remain before him in a rock, he has the power, either, by carefully extracting it, of rendering it subservient to the interests of science, or, by haste and bad management, of rendering it entirely useless. He therefore becomes either a friend to, or at best a very lukewarm cultivator of, science, according to the care he is disposed to take. He may, indeed, not be successful in his attempts; but he should at all events use the best means in his power to render himself so. When the structure of a fossil is extremely delicate, it is not desirable to endeavour to extract it from the rock on the spot: on the contrary, the observer should then strive to detach so much of the rock, no matter whether the portion be great or small, as shall, to the best of his judgment, envelope the organic remain in a protecting case of stone. And if it should have unfortunately happened that a portion of the fossil still remains behind in the rock, he should labour to procure that portion also, and so on until the whole of the organic remain in question be obtained. In all cases, he had better not attempt to clean any fossil, however apparently easy this may be, on the spot where it is obtained. The casing of the matrix or enveloping stone is valuable for the purpose of transport; and hence organic remains are generally in better condition according to the little that is done to them prior to their final deposit in cabinets and museums.

It sometimes happens that a fossil is so brittle, that

the vibrations produced by blows given to the matrix enclosing it cause it to splinter up, notwithstanding great care. If these splinters be sufficiently large, they may be marked and re-adjusted; but we should advise the observer, when he sees a fossil beginning to splinter, to take some stiff clay, if such can be procured, and press it down upon the bone or other fossil he may have before him. We have often found this plan to succeed. It no doubt would be better to employ wax or similar materials. This may advantageously be done with small specimens, and a small piece of wax may be carried about for this purpose; but for large fossils other means must necessarily be used. Upon objects of great rarity and importance, or which rest exposed in a very friable rock, which can be scarcely touched without breaking, it may even be desirable to go to the expense of preparing plaster of Paris on the spot, and cover the fossil—such, for instance, as the skeleton of a fish or saurian—with a thick coating of it. By this process the exposed part of the skeleton becomes set in a block of plaster of Paris; so that by working carefully beneath it and the fossil in the friable rock, the skeleton is eventually on a surface of plaster of Paris, from which it may afterwards be freed, or in which it may be allowed to remain, as may be desired.

When the scattered yet well-preserved bones of animals are the fossils found, it often happens that by diligent search a large portion of the entire skeleton may be eventually obtained: so that when an observer discovers a detached and well-preserved bone, he should not too hastily conclude that no other parts of the same skeleton occur near it; he should, on the contrary,

narrowly search around for other portions of it. Again, the only indication of that which has often turned out to be a most beautiful skeleton, has been a small piece of bone rising through the rock. In such cases it no doubt requires a general knowledge of the structure of the remains entombed to obtain them in a tolerably perfect condition, and a more minute acquaintance with their osteology properly to develope their various parts. It cannot, therefore, be supposed that an unpractised observer will be as successful as those who are experienced. But, from what has been above stated, the former may learn that the accidental discovery of small portions of bone may sometimes lead to that of entire skeletons, provided sufficient care be employed. In many schistose or slaty rocks, organic remains, such as fish and plants, occur in great abundance among the laminæ, pressed down to so thin a substance as not readily to be seen in a cross fracture of the stone. When therefore an observer suspects that such organic remains are included in a schistose rock, he should endeavour to strike the detached portions of it, so as to lay open the stone in the direction of the laminæ. In this way multitudes of fossil plants may be obtained, of which there were few traces in the cross fracture of the rock.

With regard to the packing and transport of organic remains much care should be taken, the more delicate and small being wrapped in cotton wool, and put into small boxes; nests, as they are termed, of which can readily be procured. The less delicate may be carefully folded in paper when not too large. The same precautions should be employed in correctly noting the localities as above

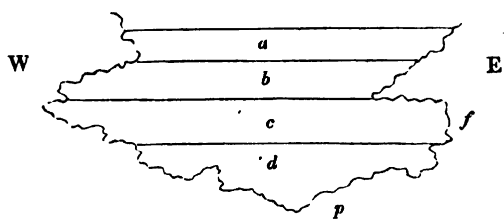
noticed (p. 249). An observer will find an angler's basket far more convenient than the sack or bag often employed for the purpose of carrying what are commonly termed hand specimens. When specimens are large and liable to be broken by any sudden jerk, such as skeletons of saurians in slabs of rock often are, we should particularly recommend the observer not to send them by conveyances without springs, if it can be avoided, and to adopt water-carriage whenever practicable.

XXIII. *Non-fossiliferous rocks, or those in which organic remains have not hitherto been detected.*—The general character of these rocks having been previously noticed (p. 9), we here proceed to offer some suggestions as to the manner of observing them. The objects sought in this case are their mineral structure and relative order of superposition.

a. For the names which have been assigned to the various mineral compounds of this class, we must refer, as before, to geological treatises. It having been supposed that beds, apparently of a mechanical origin, are sometimes intermingled with the crystalline rocks of the non-fossiliferous series, which we here strictly limit to those which occur beneath the grauwacke group of the fossiliferous class, the observer should endeavour to see how far this is true in districts which are unequivocally composed of such rocks as decidedly occur beneath the grauwacke. We say, in rocks decidedly beneath the grauwacke, because in districts of *altered rocks*, to be noticed in the sequel, and which very closely resemble those of the non-fossiliferous class, properly so called, such intermixtures are not unfrequent, owing to the unequal action of the altering cause.

b. The changes which take place in the mineralogical structure of the non-fossiliferous rocks in the direction of their strike are often highly interesting. Let us suppose that the observer is in a district composed of the rocks under consideration, and that the annexed woodcut (Fig. 124) is a map of it. Let us further suppose

Fig. 124.



the strike of the beds *a*, *b*, *c*, *d*, to be east and west, and the dip to the south at a high angle. We will now imagine that the observer carefully examines the western coast, and that he finds the beds *a* are hornblende rocks composed of little else than hornblende and felspar divided into numerous beds; the beds *b*, mica slate, composed of mica and quartz; *c*, gneiss, formed of quartz, felspar, and mica; and *d*, mica slate, the same as at *b*. Having examined this part of the coast, let us suppose that he now passes round the point *p* to the eastern coast, and finds, as he expected from the strike of the beds, that the mica slate continues to *f*, where he anticipates that the gneiss of the western coast will make its appearance. Let us imagine, instead of this happening, that mica slate still continues to constitute the coast to the northward. He might at first consider

that, from the effects of faults between the two coasts, the rocks on the eastern side had been *heaved*, as it is termed, to the northward. If, however, he continues to find nothing but mica slate until he arrives at the point where, if the strike of the beds had been constant, and no dislocations had been produced by faults, the mica slate *b* should occur, and he discovers this mica slate including, as we will suppose for the sake of illustration, a multitude of garnets, the observer is prepared to consider that there had been a modification in the mass of the non-fossiliferous rocks of the district between the two coasts; and if he find that, in the line of the hornblende rocks of the western coast, there is a schistose rock, composed, we will suppose, of mica, hornblende, and felspar, he will be somewhat confirmed in this opinion.

c. Under the above circumstances, the observer should traverse the country intervening between the two coasts, which may either be a few or many miles apart, and fairly trace, by the various natural or artificial sections which may offer themselves, the different masses *a*, *b*, *c*, and *d*, from the one coast to the other, noting the gradual mineralogical changes—for they are generally gradual—which may take place in the range of their strike. It must not, however, be inferred that because a change of mineralogical structure may take place in one or more particular masses of beds, such as *a*, *b*, *c*, *d*, noticed above, that such changes should be found in all the associated beds of the like series; for it not unfrequently happens that some beds are very constant in this respect, while others are changeable. It is precisely by noting these various differences with accuracy and in detail,

that an observer may ultimately enable either himself or others to arrive at their causes.

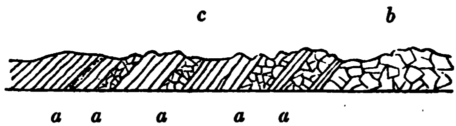
d. It will be obvious that specimens, taken to illustrate any of the above-noticed or similar changes of mineralogical structure, if selected with judgment, are important. According to calculation, the differences in chemical composition, whence much diversity of mineral appearance may arise, are often small.* As, however, calculation merely gives us an approximation to the truth, and as this approximation must depend upon the supposition that the crystalline minerals, forming these rocks, are precisely of the same chemical composition as those the analysis of which has generally been made from very perfect specimens, it is highly desirable that specimens of the rocks themselves be analysed by competent persons. An able chemist would greatly advance this important branch of geological inquiry, if he were to select a district unequivocally composed of the rocks under consideration, note the various mineralogical changes which may occur, and carefully analyse such specimens as he may consider illustrative, not only of the changes of mineral structure, but also of those rocks to which particular names have been assigned, such as gneiss, mica slate, &c.

e. The relations of the non-fossiliferous rocks with granite should be carefully studied; due care being taken not to confound the continuation of any intruded portion of the latter with a bed, or at all events a tabular mass. These tabular masses included among mica slate, gneiss with a schistose structure, and

* See Geological Manual, *Art.* Non-fossiliferous Rocks, 3rd Ed.

the like, are commonly termed gneiss when only a few feet in thickness. There are, however, theoretical considerations connected with them, that it would be out of place to notice here, which require that their connexion with any associated rocks should be correctly noted; and it should be particularly remarked whether, as in the annexed section (Fig. 125), the beds or tabular masses

Fig. 125.



of the granitic rock *a*, *a*, *a*, *a*, *a*, increase in thickness and frequency as the mass of non-fossiliferous rocks *c* approaches another mass of granite, *b*; due care being taken to see that the granite is not intruded.

f. Although it is generally considered, and apparently with good reason, that there is no definite order of superposition among the rocks of the class under consideration, that of any particular district on which an observer may be engaged should be carefully noted; and it is particularly desirable that the mode in which crystalline marble, or any other modification of carbonate of lime, occurs among the other beds, should receive attention. Care should be taken to ascertain whether such crystalline marble, or other carbonate of lime, forms a mass included among the mica slate, gneiss, and the like, or passes off into any other rock by a gradual disappearance of the carbonate of lime.

g. Due attention should be paid, in a district of the non-fossiliferous rocks, to ascertain whether all the beds,

or apparent beds, are conformable to each other, having generally the same strike or dip, or whether any portion rests unconformably upon another; proper care being taken, particularly in the latter case, to guard against erroneous conclusions from the occurrence of faults.

h. As the mode in which the rocks of the lowest part of the fossiliferous class may occur, relatively to those under consideration, involves questions of considerable theoretical importance, the observer should carefully direct his attention to those situations where the rocks of the two classes are in juxtaposition. He should note whether or not they pass gradually into each other; and if they do, then see if this be accomplished by alternations of the respective beds of each, or by the lowest beds of the fossiliferous series becoming gradually more crystalline.

XXIV. *Igneous rocks, or those which have once been in a state of fusion.*—The general character of these rocks has been previously noticed (p. 28), we therefore here confine ourselves to the manner of observing them.

a. In several parts of the world where volcanos are not now in activity,—such, for instance, as central France, and on the banks of the Rhine,—the observer will find conical heaps of cinders and ashes, and lines of rock, sometimes scoriaceous at top, diverging either from these heaps of cinders and ashes, or from less marked situations: in fact, he will see before him a state of things which more or less approaches that which he readily conceives to be one which Vesuvius, Etna, or any other active volcano, would present if their activity were to cease and the country were covered with vege-

tation. To such places the term *extinct volcanos* has been applied, though probably a similar propulsion of cinders and ashes, accompanied by the ejection of melted rock, which subsequently flowed in streams, either on dry land or beneath a moderate depth of water, took place through a long series of antecedent geological epochs.

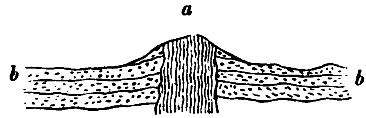
b. The observations previously suggested (p. 127) for volcanos now active will in a great measure apply also to those which have been thus, for greater convenience, termed extinct. It will be obvious that the craters, cones of ashes and cinders, and lines of melted rock, which have either been long exposed to the degrading effects of atmospheric causes, or to the action of masses of moving water, would lose more of their original characters than those which have been a shorter time exposed to the destructive power of similar agents, all other things being equal. Hence the more an extinct resembled an active volcano in a state of repose, as it is termed, the more relatively modern might we be inclined to consider it. This, however, is a conclusion which should be drawn with reference to the supposed equal action of like causes upon like products, during equal intervals of time. It therefore becomes necessary that an observer should carefully note how far any extinct volcano, under examination, bears evidence of having been always exposed to the atmosphere. If an extinct volcano has, from any geological changes in the level of land and water, either been formed beneath moderate depths of the latter, and subsequently elevated into the atmosphere, or having been in activity in the atmosphere, has at any time been exposed to the

action of tides, currents, or breakers, its relative antiquity could not be well inferred from its appearance. Let us take, by way of illustration, the case of the volcanic island of Sciacca, thrown up in 1831 between Pantellaria and Sicily. The breakers, as is well known, have washed away the accumulation of ashes, cinders, and stones which once rose above the level of the sea, and, no doubt, have acted beneath as far as their moving force can be felt: in fact, the crater has been obliterated and the volcanic accumulation rounded off.

Let us suppose that this volcanic vent continues quiet, and that, from future geological changes on the earth's surface, the volcanic mass is raised above the sea. If the rise were gradual, it would still further suffer degradation, and little would remain besides lava, now in the pipe of the vent, and any streams of the same substance which might have been thrown out beneath. We certainly do not know that there is lava in the pipe, or streams of the same substance thrown out beneath the level of the sea; but, for the sake of the argument, we may readily assume this as an hypothesis. There will be no difficulty in considering that this elevation might be accomplished within a portion of time insufficient to cause any great change in the present condition of some of the extinct volcanos of Auvergne. It will be clear that if an obliterated crater be always taken as conclusive evidence of the greater antiquity of one volcano than of another, of which the crater was somewhat perfect, there might come a time when it would be assumed, that the relative antiquity of the volcanic accumulation in question was greater than that of several extinct volcanos in Auvergne.

c. It being considered that igneous rocks have been ejected from the interior of the earth both in the manner of modern volcanos and in large masses, the observer should direct his attention to those points which illustrate this subject. The name *trappean* has been assigned to various rocks, such as greenstone and the like; and the term is exceedingly convenient, provided it be not assumed that such rocks have always been thrown up in mass, and in a manner different from that in which melted rock is now ejected from a volcano, or compelled to enter into and fill up the cracks produced in and around it. We have entered more at length than we should otherwise have done upon the changes which might be produced on the former island of Sciacca, if it were so washed, either gradually or suddenly, by the sea that its harder parts only remained, because we consider we have seen situations in which trappean rocks have been so covered over by, or intermingled with, deposits of aqueous origin, that the washing away of the softer parts of a volcano, and the subsequent envelopement of the harder by aqueous deposits, would best explain the undisturbed condition and apparently unchanged character of the latter. Let us suppose that an observer meets with an isolated portion of some igneous rock, of a somewhat oval form and of very moderate size, rising in the midst of a district of sandstone and conglomerate; and let us further suppose that, searching for evidence of disturbance among the sandstone or conglomerate beds, he finds none, and that no change moreover can be seen at the junction of the sandstone or conglomerate and the trappean rock, which latter he discovers by natural or arti-

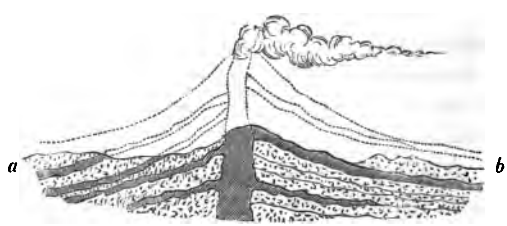
Fig. 126.



ficial sections, such as that above (Fig. 126), to rise like a column through the beds of aqueous origin, *b*, *b*. He should now carefully examine the contents of the conglomerate beds; and if he finds fragments of the igneous rock included in them, he may fairly conclude that the trappean mass stood isolated in water, and was gradually enclosed by beds of sandstone and conglomerate, some of the materials of which were at least derived from its partial destruction. The trappean rock, in such a case, would clearly be more ancient than the rocks surrounding it.

d. We have endeavoured, in the foregoing illustration, to illustrate a somewhat complicated subject in its simplest form: it is, however, a form less frequent than the more complex. Let the observer now imagine that the annexed sketch (Fig. 127) is a section of a volcano, in which the vertical shaded part represents a

Fig. 127.



column of lava rising in the pipe or vent, and the sloping and horizontal shaded portions lava-currents which have, at various times, proceeded from the main pipe, so that when the lava in the latter became finally consolidated they would in some measure be joined to it. Let the dotted and unshaded parts represent beds of cinders, ashes, and stones, which are mingled with the lava-currents in a kind of irregular stratification. Let us now suppose that degrading surface-causes so act upon this mass of consolidated melted rock, and beds of ashes, cinders, and stones, that the line *a b* becomes the surface of the land, and we have a kind of trappean hill rising among beds of conglomerates, sandstones, and the like; some of the lava-currents, when viewed on the surface, appearing like beds of trappean rock interstratified among the conglomerate and sandstones. These effects will be greatly modified if the volcano has been sub-aqueous, and the modifications will be greater according to its depth beneath the surface of the water. Such effects would not be confined to one geological epoch, but would be common to all in which the various products could be arranged by volcanic action in the manner above noticed.*

* We have here neglected the fact, that the lava-currents would be braced together by dykes of lava, rising through cracks in the body of the volcano, and that thus the lava-skeleton, if we may use the expression, of a volcano, if all beds of ashes, cinders, and ejected stones were removed, would consist of a main trunk, from which numerous radiating lines descended in an inclined manner, so that the general appearance would be conical, and these radiating lines would be bound firmly together by numerous tabular plates, for the most part highly inclined, connected with the main trunk. These, no doubt, are subjects which should be attended

When an observer considers that any trappean rocks he may have before him may have been ejected in the manner of lava-currents, or be the remains of the consolidated contents of the pipe of a volcano, he should first see if they be in any way associated with conglomerates or breccias; and if they are, he should carefully search for fragments of the trappean rocks in them. Should he find evidence that the conglomerates or breccias are of more modern production than some of the trappean rocks, it remains to be seen whether they have been formed after all the same rocks of the locality were produced. He should recollect that the conglomerate or breccia beds may either have accumulated round, and have been intermingled with, the once melted rocks, after having been shot up in the shape of ashes, cinders, and stones, into the atmosphere; be formed by the action of water, in the case of sub-aqueous volcanos; or result from both these causes. In cases where the action of water has produced the arrangement of the ashes, cinders, or stones, into beds; mud, sands, and stones, derived from non-volcanic rocks, may readily be mingled with them in such a manner that the *angular* fragments of the trappean rocks may be associated in the same bed with the *rounded* pebbles of non-volcanic rocks derived from a distance. An observer should therefore direct his attention to this point, and should carefully notice if the fragments of trappean rocks occur only around the masses of trap first noticed, gradually disappearing as he recedes from them;

to; but a detailed notice of them in the text would only make a complicated subject still more difficult to an inexperienced observer.

the continuation of the conglomerates, if they exist, affording only pebbles or fragments of other rocks. He should endeavour to discover if there are any traces of volcanic sands among such associated beds; and as lava-currents, if sufficiently thick, may alter the rocks over which they flow, he should look for traces of such alterations in the beds immediately beneath any mass of trap associated with the marl, sandstone, or conglomerate beds, as the case may be, while he would not expect to find any alteration in those above, since the latter were accumulated after the lava-current ceased to flow from the absence of the necessary heat.

In order that the observer may not suppose we have dedicated too much of our limited space to a notice of circumstances which scarcely ever occur, because they have hitherto received little attention, we may state that in the neighbourhood of Tiverton, Silverton, Kellerton Park, and Crediton, in Devonshire, facts similar to those above noted are observable; and there seems good reason to consider that, in that district, volcanos existed at the period of the new red sandstone, which continued in activity while the lower part of that series was forming, and that probably such volcanos were situated in a manner, relatively to sea, not very unlike that of the island of Sciacca. Mr. Murchison has noticed phenomena which he considers may be well explained by volcanic action contemporaneous with the production of the grauwacke of part of Wales,* and we have done the same with regard to the same rock in Devonshire.†

* Proceedings of the Geological Society of London, 1834.

† Researches in Theoretical Geology, p. 384.

e. Although volcanic action—that is, the forcing out of ashes, cinders, stones, and melted rock upon the earth's solid surface by means of gases and vapours, and the injection of melted rock into cavities and fissures,—may have taken place from very remote periods, geologically speaking, it does not follow that the propelling gases and vapours have always been the same, or that the rocks thrown out have possessed a like mineral structure. As the observer cannot learn how far the propelling gases and vapours may have differed, he can only direct his attention to the mineral structure of those rocks of which the mode of occurrence is such that they may readily have been ejected in the manner of modern lavas. He will often meet with amygdaloidal rocks among these, and by attention to the direction of the vesicles, now filled with agates, carbonate of lime, or other mineral substances, he may learn that in which the current of the trappean rock flowed, when in a fluid or viscous melted state. These amygdaloids show that they have not, until consolidated, been exposed to any great superincumbent pressure; their presence therefore among other associated trappean rocks is important. We have seen some of this kind of igneous rock, associated with greenstones among grauwacke, which were so vesicular that they must, before foreign matter filled up the little cavities, have resembled a light pumice-stone. In one particular instance, a few miles south from Launceston (Cornwall), the infiltrated matter, which happened to be carbonate of lime, was so abundant, and the walls of the vesicles so thin, that the rock has been successfully worked as a limestone.

The observer should carefully note the various mineral characters of these supposed volcanic rocks of different ages, and take specimens of such as appear to be characteristic: he should also see if the mineral character be very different in the same locality. As these pages may probably pass into the hands of many who have not hitherto consulted works on geology, we should state that the chemical composition of an igneous rock may often be the same while its appearance differs, and that a piece of greenstone may be converted into a vitreous substance like obsidian by melting it and suffering it to cool rapidly in our furnaces;—that such vitreous substance may be again reconverted into stone by such management, that after being again fused it should cool slowly; and that in proportion as we can command slow cooling, we obtain a greater amount of crystalline structure. In proportion, therefore, to the crystalline structure of igneous rocks of the *same* chemical composition, may an observer assume the greater length of time for their cooling, and consequently conditions necessary to produce this effect.

f. The observer must not infer, because a trappean rock has been once full of vesicles, the infiltration of foreign matter into which has now converted it into an amygdaloid, that it, and any other trappean rocks associated with it, have necessarily been ejected in the manner of lava from a volcanic vent; for if it formed the upper portion of a trappean rock, thrust up in mass, either fluid or viscous, from beneath, it might readily take the vesicular character when the superincumbent pressure was insufficient to prevent any gas or vapour, disseminated through the rock, from expanding.

g. We now come to the consideration of those igneous rocks which neither in themselves, nor in their general mode of occurrence, present us with any evidence of their having been ejected in the manner of lava from a volcanic vent: on the contrary, the evidence respecting them tends to show that they have been thrust upwards among other rocks, in a state varying from considerable liquidity to a viscosity approaching solidity, and often in large masses. Let us, for instance, take the granites properly so called, and clearly intruded among other rocks. Hitherto nothing has been adduced to show that these granites have been ejected from anything resembling a volcanic vent, while there is much to render it probable that they have been thrust upwards in great masses, displacing other rocks, which, when stratified, are often folded up or contorted around them. The same may in numerous cases be said of masses of serpentine, diallage rock, various porphyries, greenstones, &c. By this statement we merely wish to place before the observer that which may be fairly deduced from known facts. We should depart from the course we have traced for ourselves in these pages if we attempted to bias his opinions by this or other inferences; he should therefore only receive such as are given conditionally, until his own researches may enable him to judge how far they may, or may not, be correct.

h. When an observer has a mass of granite, serpentine, diallage rock, porphyries, greenstones, and the like, before him, he should endeavour so to conduct his researches, that while he attentively considers all those circumstances which might lead to the inference that

they have flowed from volcanic vents in the manner of lava-currents, or that they have been thrown up in masses, he should at the same time note if there be any veins shooting, as it were, from the main body of the igneous mass into the adjoining rocks; and if so, whether such veins appear to fill up rents and fissures produced in the latter. Due care should be taken to notice the gradual change of mineralogical structure in such cases; it being borne in mind, that if there be good evidence to show that the matter of the igneous mass has been forced into crevices and fissures in the pre-existing and adjoining rocks, the same chemical compound, which may appear large-grained and highly crystalline in the main mass, may readily form a more compact substance towards the termination of a vein outwards; the simple reason being that, in the latter case, the compound would be exposed to conditions under which it would cool much more rapidly than in the principal mass. Specimens of these changes are always desirable for the purpose of analysis.

i. We may here again call the attention of the chemist to the great assistance he may render to geology by the analysis of portions of rock. We have elsewhere* calculated certain differences and resemblances which may exist in the chemical composition of various igneous rocks: as, however, such calculations are mere approximations, which may be more or less close according to the correctness of the data on which they are founded, we require more direct evidence of such differences or resemblances — and this can be best afforded by the experienced chemist. There can be little doubt

* Geological Manual, *Art.* Unstratified Rocks, 3rd Ed.

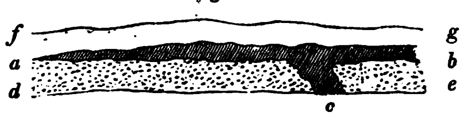
that igneous rocks, composed chemically of the same substances, have often been distinguished by names which would lead many to infer that they were not, as they are, mere modifications produced in the same mass of matter. Let us, for instance, take a compound of substances forming the minerals named hornblende and felspar, so that when the two minerals can be properly developed they each constitute one half of the rock. If this compound be exceedingly fine-grained, it would very frequently be termed basalt; if the minerals were well developed, a greenstone; and if so developed as to constitute a large-grained rock, a sienite,—at least, the latter name is often applied to such a rock. Again, if the same substances should so arrange themselves that a mineral shall occur in a perfect, or nearly perfect, crystallized state, disseminated in a base composed of the remaining chemical substances, it would be termed a porphyry. These changes in the mineral structure of the igneous rocks should engage the attention of the observer; and he will not unfrequently find that they take place in very limited distances in the same mass—one which has evidently been ejected or thrust up at the same time. Specimens illustrative of such changes are valuable for the purpose of analysis, and therefore should be collected with care.

k. In dykes (p. 30), the observer should direct his attention to the various changes of structure that may be noticed in them. It has been found that the outer parts of dykes, composed of greenstone, sometimes pass into serpentine, when the rock traversed is a limestone. The passage of serpentine or diallage rock into greenstone is also frequent when the former occur in large

masses. These and similar points should not be neglected.

l. The observer must in a great measure be guided, in examining the occurrence of igneous rocks relatively to each other and to those of aqueous origin, by the kind of country he may be in; and as this varies exceedingly, it would be difficult to direct him how to act. He should, however, particularly direct his attention to any evidence there may be of the igneous rocks having cut through or disturbed the district generally, or of their having been injected among the strata or beds of pre-existing rocks. It must frequently have happened that igneous rocks, discharged through fissures, or more or less extensive vents, have flowed over the then existing solid surface, and that the whole has been since covered by some rock of aqueous origin. Let us suppose that in the annexed section (Fig. 128), *a b* is an igneous rock,

Fig. 128.

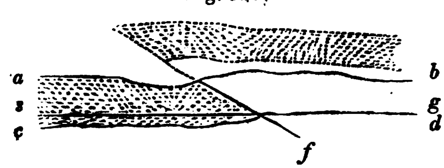


which has been ejected through the vent *c*, so that it overflowed the surface of the pre-existing rock *d e*; and that after the consolidation of this igneous rock, the aqueous deposit *f g* was formed upon it. Now, as the same general appearance might be exhibited if the igneous rock *a b* had risen through *c*, and meeting with considerable opposing force from the rock *f g*, took a line of less resistance, which we will suppose was that between the rocks *d e* and *f g*, so that it became in-

jected between them; it is necessary that the observer should minutely notice the condition of the under surface of *f g* and the upper surface of *d e*. If these surfaces both exhibit effects which may fairly be attributed to the action of the heated rock upon them, or fragments from both be included in *a b*, then it may be inferred that *a b* has been formed after *d e* and *f g*, and has been injected between them. If, on the contrary, the upper surface of *d e* alone offers any appearance of having been acted on by heat, and that the lower surface of *f g* perfectly conforms to the upper surface of *a b*, little lines of structure, or of stratification, showing that *f g* has moulded itself upon a pre-existing surface of *a b*, perhaps even containing small fragments of the latter, it may be inferred that *a b* is an older rock than *f g*. If, now, *f g* and *d e* be two known rocks of a series, the relative age of *a b* will be also known.

m. To judge of the relative date of igneous rocks, when sections are somewhat obscure, requires care. Let, in the annexed section (Fig. 129), *a b* represent the

Fig. 129.



surface of a country; *c d*, another line, beneath which no sectional view of the rocks can be obtained; *s*, some supracretaceous sandstone; and *g*, granite:—it might at first view be assumed, that the granite had overflowed the supracretaceous rock, and was consequently more

modern than it. In the case before us, the inference would be incorrect; for the granite may have been of the oldest kind, covered, as all older rocks may be, by one formed long posterior to itself; the apparent superposition having been caused by the fault *f*, which is by no means more inclined than some faults are, and the subsequently produced surface having been so formed as to give the false appearance of superposition in this locality. We give this illustration, not because such facts may often occur, but to place the observer on his guard, when important inferences relatively to the date of rocks may be drawn, so that he employ considerable caution. The obvious course, in the case of the illustration before us, would be to search for evidences of a fault between *s* and *g*, and endeavour, either from natural or artificial sections, to see if any continuation of *g* may be obtained beneath *s*, either in the prolongation of the surface line of junction between the two rocks, or by at once passing through *s* in search of *g*.

n. It being commonly supposed that there has been a change, viewing the subject on the large scale, in the chemical character of the igneous rocks, producing a corresponding change in their mineralogical structure, between the older geological periods and the more modern,—that is, that the rocks ejected and thrust upwards in a melted state were not formed of precisely the same mineral substances in the earlier conditions of the earth's surface, as at more recent epochs,—the observer should be careful not to neglect opportunities of obtaining the relative ages of the igneous rocks whenever they present themselves. This is to be accomplished by noting their mode of occurrence relatively to the

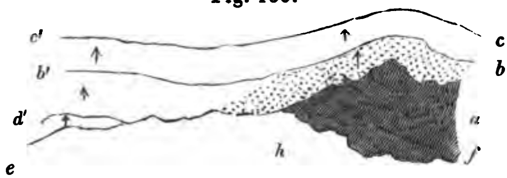
rocks of aqueous origin. When it can be determined that they, or rather that certain of them, repose upon, or cut through, any rock of which the relative age is known, it follows that the particular igneous rocks which do so are more modern than those aqueous rocks on which they rest or through which they cut. When they are quietly covered by aqueous rocks of known relative date, they are known to be more ancient than the latter.

XXV. *Altered rocks.*—Although there are few rocks of mechanical origin which have not been in some degree modified in their structure since the period of their original deposit,* the term *altered rocks* is at present exclusively applied by geologists to that modification of mineral structure which has taken place in rocks, since their production, through the agency of heat; it being understood that the heat has never been sufficiently intense to produce fusion, and, therefore, if the rock has been stratified, that it retains that structure, the alteration having been solely produced in the position of the component particles relatively to each other.

a. When the observer suspects that he has altered rocks before him, his first care should be to trace those that he may consider such to situations where their characters shall be altogether unequivocal. Let us suppose that the annexed sketch (Fig. 130) represents a map of a district, *e f* being a line of coast, and that the observer is passing along it from *f* to *e*. Let us further consider that *a* is granite, and that arriving at *h*, he finds a rock in contact with it which at first sight he

* See Researches in Theoretical Geology, p. 91.

Fig. 130.



considers to be gneiss, but upon reflection suspects may be an altered rock, from the general geological character of the district. He might first trace the supposed gneiss round to *b*. We will imagine that he does so, and finds its characters constantly the same; and, moreover, discovers a fossiliferous rock, *c*, resting upon it. He will still continue in uncertainty, because he has followed a direction where, if the rock were altered, the conditions for producing this alteration would be the same; and therefore he would learn little more than if, when at *h*, he had gone into the interior and ascertained the kind of rock which rested upon the supposed altered rock *b*, the dip of the latter being in that direction.

The course of the observer should be in the direction of *e*, away from the granite, which for the sake of illustration we must suppose not to be continued, even beneath the sea, in that direction. He must now carefully search for changes in the mineralogical character of the rock he is tracing, and be on his guard against the substitution of another rock in its place in the line of strike. To illustrate our subject, let us consider that he gradually observes the character of gneiss to pass away, and that, as he recedes from the granite, the rock passes into an argillaceous slate. He should endeavour to learn if this slate be fossiliferous: if it be

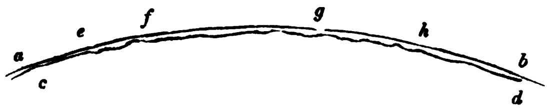
so, he may set down the rock *b* as altered when in contact with the granite. This necessarily implies that the slate is an older rock than the granite, and that the latter has been brought into contact with the former in a state of fusion or great heat. Hence, still further to convince himself that an alteration in the rock *b* has been caused by the granite, he should carefully search for evidence of the intrusion of the latter into the former.

In the foregoing plan (Fig. 130) we have supposed the altered rock to be included, in the direction *e*, between two rocks, *c'* and *d*. Now, if these be known rocks of a series, either from being fossiliferous or from other circumstances, the relative age of *b b'* will be known, and the observer will learn that such rock has been altered, and puts on the deceptive appearance of gneiss, when in contact with the granite *a*.

The observer should in all cases, whether on the small or large scale, have good evidence that a rock is altered, by tracing it to situations where it is unaltered, or by finding organic remains in it which are known to occur in given rocks of the district, or in those of a known series; the proximity of an altering course, within a reasonable distance, being sufficiently evident.

b. It is not enough that a given rock merely changes its character,—such, for instance, as from mechanical to crystalline,—thence to infer that the crystalline are altered portions of the other parts. It may readily happen that, in certain extensive deposits, one part is formed mechanically and another chemically, part of the latter being highly crystalline. Let the arc *a b* (Fig. 131) be the level of the sea over an extensive

Fig. 131.



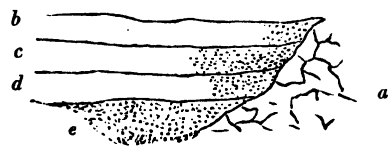
area, and *c d* the solid bottom beneath it. There will be no difficulty in conceiving that a contemporaneous deposit effected on the latter may be sand at *e*, mud at *f*, common limestone at *g*, and crystalline limestone at *h*; or that there may have been great variations in this respect throughout the whole distance. Hence, if by accident the crystalline limestone were formed upon a pre-existing mass of igneous rock, and were subsequently elevated above the level of the sea, it might, without sufficient care, be assumed that such crystalline structure was produced by the former heat of the igneous rock, and such crystalline rock an altered one.

In the cases of certain dolomites (a compound of crystalline carbonate of lime and carbonate of magnesia) and crystalline limestones, this caution is particularly necessary; since, though there is often sufficient evidence to show that rocks possessing these characters are altered, there is also evidence that others of a similar character have been originally formed as we now see them.

c. When the alteration of rocks is a fair inference from the facts noticed, the observer should pay great attention to the kind of alteration produced, taking specimens which are illustrative, more particularly for the purpose of chemical analysis, in order that it may be seen whether the same component parts are present

in all, or whether foreign matter has been introduced into that of the original rock during the process of alteration. When, moreover, several beds, varying in mineralogical structure, are cut by the same mass of igneous rock, and they have all been altered, he should attend to the relative alteration of each, noting how far the original mineral structure has modified the amount of distance to which the alteration may be traced in each. Let *a*, in the annexed plan or section (Fig. 132), it is immaterial which, be an igneous rock

Fig. 132.



which has cut through several beds or rocks, *b*, *c*, *d*, *e*, and let each of the latter differ mineralogically from the other; then he should note whether, due allowance being made for the curves of the junction line between the intruded and pre-existing rocks, they are altered to various distances, — and if so, carefully distinguish the mineral structure of each. We have above supposed and shown by dots, that *e* has been altered to the greatest distance, and *b* the least.

d. In all cases of dykes composed of granitic, trappean, or common volcanic rocks, it is desirable that search be made in the adjoining rocks for alterations in their structure. This often takes place, and is disregarded because the alteration so produced is on the small

scale. It is, however, highly instructive; and it is desirable that the observer should see if any reciprocal action has been produced upon the matter of the igneous rock itself. We have already stated that such action may be found under certain conditions, and it probably takes place more than has hitherto been remarked. We have observed changes on the large scale which would seem to require this kind of explanation.

e. It must not be supposed that alteration of rocks, in the sense above noticed, has been confined to those of aqueous origin: they may sometimes be found where one mass of igneous rock has cut through another and pre-existing mass. The changes then produced are often highly interesting, and such as the observer should by no means neglect.

XXVI. *Metalliferous veins.*—In accordance with the usual custom, we confine the above name to those veins which contain metals employed for useful purposes. The definition is, however, far from good, since the ores of metals—such, for instance, as iron pyrites—occur alone in situations illustrative of at least some kinds of metalliferous veins. It is by no means our intention to enter at length upon this complicated subject; we merely desire to call the attention of the observer to one or two prominent points.

a. It being considered that many metalliferous veins are but the fractures usually termed faults (p. 199), and that the ores of the various metals found in them have been subsequently introduced, the observer should direct his attention to such circumstances as would characterise the relative position of the sides of the vein and its contents, if such were the case. He will search

for evidence of movement in the sides, marks of friction, fragments of the adjacent rocks in the fissure, and other circumstances previously noticed (p. 200). He would do well, when opportunities offer, to study the occurrence of iron pyrites in common faults, and note how far there may be any difference between such mode of occurrence and that of the ores of copper or of other metals, as the case may be.

b. It has been noticed in some countries, and we have had occasion to remark the same thing, that a metalliferous vein or lode ran parallel, or nearly so, to a great fault, and that the former appeared like a crack produced when the neighbouring great fracture or dislocation was formed. This also is a circumstance to which the attention of the observer should be directed.

c. Metals also occur in a kind of network formed of numerous strings of ore, which cross each other in all directions. These have by some been considered as contemporaneously produced during the consolidation of the rock; while others regard them as a multitude of small cracks formed in the containing rock during consolidation, into which the matter of the ore was subsequently introduced. The observer should without bias endeavour to note the various facts connected with such modes of occurrence.

d. Metals, again, are disseminated through rocks in grains, which are for the most part crystalline. The oxide of tin is thus sometimes disseminated in granite, and gold has been so found in some porphyries. In such cases, the observer should be careful to note whether the disseminated metals appear to have crystallized out in the manner of iron pyrites in some trap rocks,

or in the manner of the same substance in mechanically produced marls, clays, and slates. He should also be careful to ascertain whether the grains may have been the detrital portions of pre-existing metalliferous veins, such grains having been washed onwards with the other parts of a mechanical rock until finally brought to rest with them.

e. As it every day becomes a more prevalent opinion, from an increased stock of facts, that the metals in veins have been derived from the rocks which contain them, the observer should direct his attention to the condition of the containing rocks in the vicinity of the veins, noting if there be any difference in their mineral structure near the veins, and at some little distance from them. In cases where such differences are observable, specimens are desirable, more particularly for the purpose of chemical analysis.

f. As the same lode or metalliferous vein is observed in all mining districts to vary more or less, viewing the subject on the large scale, according to its range through different rocks, or even through the same rock, when the latter varies in mineral composition, or even in hardness, the observer should carefully note the kind of changes thus effected, and remark how often a similar mineral structure is associated with a similarly characterised vein. By obtaining a mass of classified facts of this kind, more insight into this subject may be eventually obtained than we now possess.

g. Remarkable facts are often observable at the crossing or intersection of two or more metalliferous veins, more particularly with regard to the kind of metals found, and to their association, as also as respects

the shifting of the general planes of the lodes or metalliferous veins. In the latter case, particular attention should be paid to any resemblance there may be between such facts and the crossing of faults of different ages, the continuity of one set of faults being then destroyed by the shifting caused by the crossing of another set.

h. It having been frequently remarked that metalliferous veins are abundant at the junction of an unstratified with a stratified rock, when the former has been intruded among the latter, the observer should carefully note, when metalliferous veins traverse both rocks, the distances to which particular characters of the lodes, and the abundance of ore in the veins, extend on either side of the junction line between the stratified and unstratified rock.

PART III.

APPLICATION OF GEOLOGY TO THE USEFUL PURPOSES OF LIFE.

I. *Agriculture.*—It would be difficult to find an intelligent farmer, in a district where rocks of variable mineralogical characters occur, who does not, to a certain extent, practically know that the value of each soil respectively depends upon the kind of rock beneath it. He may not know, and scarcely ever does, why this happens; but the fact itself is familiar to him. Now, it is precisely a knowledge of why this happens which enables a geologist, acquainted with the mineralogical structure of a given rock in a district, to state that the soil formed upon it will, under equal circumstances, better support one kind of cultivation than another. In some cases, the lines separating particular kinds of cultivation are precisely those which separate two rocks beneath them; the agriculturists having found, from experience, that the two soils above these rocks will not support the same cultivation with equal advantage. The common country division of soils into heavy, light, cold, and the like, depends upon the kind of rocks beneath them.

Natural soils are merely decomposed parts of the subjacent rock, mixed with the decomposed portions of vegetable substances, which have grown or fallen upon it, and with a proportion of animal substances derived from the droppings of creatures which have fed upon

the vegetation, from dead insects and worms which once inhabited the surface, and from the decomposition of animals that have perished on the land, and which have not been altogether removed by those quadrupeds, birds, and insects that act as natural scavengers.

The permanency of natural soils depends upon the relative positions they occupy (such as whether they are formed on the steep slopes of hills or on level plains); upon the porous or impervious character of the supporting rock as regards water (whence the difficulty or facility with which the soil may be washed away during rains); upon the climate generally of the locality, more particularly as regards the quantity of rain which may fall in a given time; and upon the kind and amount of vegetation upon them, by which they are more or less protected from removal according to circumstances.

Although some plants grow without having their roots plunged in the soil, this, as is well known, is not the case with vegetables generally, nor with those cultivated by man, either as food for himself, or for those creatures which he has domesticated. If we consider the leaves as the lungs, the stems as the bodies, and the roots as the mouths of plants, it will be evident that a plant cannot obtain the same food from soils which differ materially from each other. As animals perish, draw on a miserable existence, or thrive, according to the food given them, so do plants; and if the agriculturist force a given kind of plant into a situation where it cannot obtain the nourishment for which its various parts were constructed, it cannot thrive. Now, as one kind of food is proper for some animals and not

for others; so, with plants, the soil which will nourish some is improper for others. Hence it becomes necessary that the agriculturist should know the kind of soil best suited to each plant he may cultivate; and as the character of soils mainly depends upon the rocks of which they are chiefly the decomposed portions, a knowledge of the mineralogical structure of these subjacent rocks, and of their general mode of occurrence, can scarcely be less essential to him.

The mineral substances forming masses of rock are not very numerous; and while some decompose readily, others retain their original structure. Both characters are often highly valuable in a soil; the undecomposed portions keeping it *open*, as it is termed,—that is, allowing the free dissemination of air and water,—while the decomposable parts unite in various ways with or modify the food of the plants. Thus, a due admixture of silica in the shape of sand is often highly valuable, while a proper allowance of carbonate of lime tends to neutralise any acetic or other noxious acid which may be present in a soil, that is then technically termed *sour*. The name *humus* has been given to the vegetable and animal matter mixed with the mineral ingredients of a soil. To this important part of a soil a rock can only indirectly contribute; but there will be little difficulty in conceiving, that the greater the ability of a rock to afford a decomposed mineral mixture which should suit the greater quantity of vigorous and luxuriant plants, the greater would be the probability of a larger amount of humus in the superjacent soils. Not only would the probability of a larger amount of vegetable humus be greater, but the chances of a larger

amount of animal humus would be increased from the greater mass of insects, reptiles, birds, and mammifers, which would either feed upon, or shelter themselves among, the more luxuriant vegetation. This *à priori* reasoning is borne out by facts; since it is found, that under equal circumstances as to climate and other conditions, a mineral mixture which suits a larger amount, or the more luxuriant parts, of a given vegetation, will be that associated with the greatest relative amount of *humus* in a natural soil.

We must refer to the article on AGRICULTURE for the connexion between particular soils and the plants grown upon them, and content ourselves by noticing the dependence of the character of the soil upon the subjacent rock. No one would expect that *all* the plants cultivated by the agriculturist could grow equally well upon the chalk of eastern England, on the red marls and sandstones of the central and western counties, and on the grauwacke of Devon, Wales, and Cumberland. We should, however, observe, that it is upon the mineralogical structure, not the geological age of rocks, that the barrenness or fertility of the superjacent soils depends. Taken, however, as masses of matter, the mineralogical structure of rocks is sufficiently constant throughout moderate areas, so that if it be known as respects one part of an area, the other parts will not be found to differ materially. Hence, the agriculturist who examines a good geological map, comprising a moderate area, may feel assured that the respective soils, upon the various rocks traced upon it, will possess the same general characters under equal circumstances. If geological maps be, as probably they will be, improved

by the insertion of symbols or signs in different places, showing the mineralogical structure of the rocks at such places, the information afforded to the agriculturist will be still more complete.

a. As a soil, composed of the same mineral substances, is of very different value to the agriculturist according as it is either wet or dry, the observer should direct his attention to those circumstances which render it either the one or the other. Disregarding for the present the general surface-drainage of a country, the dryness of a soil depends, under equal evaporation and supplies of rain, upon the facility with which its particles permit the percolation of water downwards, and this facility upon the kind of rock beneath, as above noticed. Sandstone rocks generally, as might be expected, afford a dry soil. This, however, is not the case with all arenaceous rocks. In some, the mineral matter cementing the particles of sand together, is so aluminous and abundant, that when the rock is decomposed, the clayey matter overpowers the sand, and a heavy tenacious soil is the result. When the observer finds that the subjacent rock of a dry soil is porous and sandy, his remedy for this kind of soil, if it be desirable, will be to do something which shall retain moisture in the soil itself as long as may be convenient; since, once arrived at the subjacent rock, it will be absorbed freely by it. Some addition must therefore be made to the soil, either of a substance which readily absorbs moisture from the atmosphere, to be consumed by the vegetation, or of a mineral substance which shall bind the particles of the soil more firmly together, so that, in a given time, a much less quantity

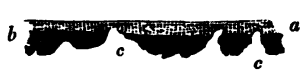
of water shall pass downwards to the absorbing rock than if no such mineral substance had been added. Soils thus circumstanced may be considered as well drained beneath.

When a dry soil is the produce, by decomposition, of a rock which does not freely absorb water, additions to it, for the purposes of rendering it more moist, require very great care. The observer will generally find such soils shallow, and liable to be washed away by rains. The rains run speedily off where the physical features are favourable, and the soil soon becomes dry from evaporation. It is not a little interesting to observe the excellent effect produced on such soils by the loose stones, not unfrequently scattered over them. These retain moisture in the soil by preventing the evaporation which would otherwise take place; and it is often not a little curious to note the differences of corn-crops on two adjacent farms, when the occupant on one has removed the stones, and the other has allowed them to remain, the advantage being so greatly in favour of the latter. With regard to scattered stones on dry soils generally, it may be stated, that there are some of the latter so porous that sufficient moisture would not remain in them to reward the agriculturist for his labour, if they were not abundantly covered with scattered stones. In high lands they also serve to condense fogs and low clouds, and thus add to the moisture of the subjacent soil.

b. A wet or heavy soil mainly depends upon the quantity of clayey matter afforded by the rock beneath it. The latter is very often, under such circumstances, a clay itself, or an argillaceous rock readily converted

into such a substance by the addition of sufficient moisture. The soil, therefore, is held up by a sheet of rock impervious to water, and the necessary effects must follow. Such soils are, however, scarcely ever good in themselves; but a good soil may be, and occasionally is, supported by a bed of clay,—the good soil being due to the decomposition of a bed or stratum, the mineral character of which was of the proper kind. The bed of clay, or other bed impervious to water, will, if the soil be not sufficiently thick, cause the latter to be wet, and unfit for purposes to which it might otherwise be dedicated. The observer should ascertain the thickness of the clay or other bed, and the nature of the rock beneath it. If the bed of clay, supposing it to be such, is not too thick, and the stratum beneath be porous, he will be able, from the geological and physical characters of the country, to judge whether it may be better to pierce through the clay bed in many places, leading radiating drains to the holes thus formed, or drain generally in the usual way. When there is an extensive and elevated table-land, here and there cut by deep valleys, the former might be the cheaper plan, though probably it has never, except accidentally, been carried into practice. We have seen parts of a table-land formed of a fair though gravelly soil, *a*,

Fig. 133.

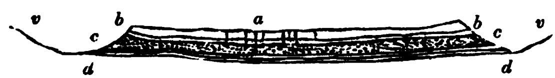


resting upon a tenacious clay, *b*, drained naturally upon this principle, by means of pinnacles of chalk, *c*, *c*,

which pierced through the clay in several places, and entered the gravelly soil above. The portions of soil above and near the chalk pinnacles were kept fairly drained by the well-known property of chalk readily to absorb moisture, while those portions of the soil which were too far from the draining influence of the pinnacles, were wet and heavy.

If, upon the same principle, an agriculturist should find it difficult and costly to drain a soil, placed under the conditions above noticed, in the usual manner, and that the part to be drained is situated as at *a* (Fig. 134);

Fig. 134.

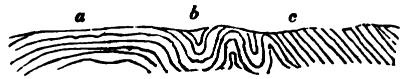


if he can deliver the water into the porous rock *c c*, by drilling numerous holes in the clay bed *b b*, such water would tend to percolate through the bed *c c*, and be delivered in springs into the valleys, *v v*, if *c c* be supported by a bed, *d d*, impervious to water. If the water be not stopped by such a bed, then it will continue to percolate through the inferior mass in the usual manner. To know that the proper conditions obtain, necessarily requires competent geological observation.

c. When an observer finds a heavy soil produced by the decomposition of hard rocks, such as certain sandstones and slates of the grauwacke series, or others of the like mineralogical structure, be their geological age

what it may, he should direct his attention to the stratification of the rocks affording the principal materials for the soil, since the practicability of ameliorating the latter much depends upon this circumstance. Let us suppose that the annexed section (Fig. 135) repre-

Fig. 135.



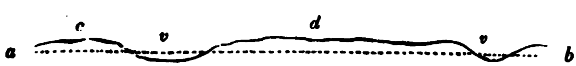
sents the stratification of a series of rocks affording a heavy clay soil, so that the beds are horizontal at *a*, contorted at *b*, and dip at a considerable angle at *c*. Now, supposing them to be, as they generally are, nearly impervious to water as beds, and that the soil is attempted to be made lighter by artificial means over the whole surface *a b c*, very different success will attend the experiment at *a* and at *c*, because a water-supporting surface will still continue beneath the soil at *a*, while the interstices between every bed at *c* will serve to drain the land. Consequently, if the soil be so lightened that water can freely percolate down to the edges of the beds at *c*, due care being taken to lay open such edges by lines of drains, so that the upper portions of the interstices are not choked by particles of clay, the soil may be rendered far more dry than before. If an observer direct his attention to two soils derived from similar rocks, the one situated upon nearly horizontal strata, and the other upon the edges of highly inclined beds, he will frequently perceive that the

former may be heavy and the latter comparatively light, for the simple reason that one is naturally drained and the other not.

d. Although a geologist may feel satisfied that a porous rock is situated beneath a water-supporting stratum, near the surface of land, the agriculturist can scarcely be expected to be aware of the structure of the rocks beneath the few feet to which, in his deepest ditches, he is in the habit of working. He may, however, greatly advance himself in a knowledge of circumstances that may often prove highly valuable to him, by consulting good geological maps, constructed on a large scale, which will give him the *surface* of land occupied by any given rock, and then turn to the sections which ought to accompany such maps, which will show him how the rocks occur relatively to each other beneath the soil. Let him now consult the memoirs written to illustrate the map and sections; and by carefully combining the accounts given of the structure and composition of the rocks, as noticed in the memoirs, first, with their relative position as shown in the sections, and secondly, with the portions of surface occupied by each respectively, as shown by the maps, he will obtain, without embarrassing himself with those questions which relate to the higher branches of geology, a stock of knowledge respecting the rocks beneath the soil in given districts, which he can readily turn to good account in his management of land, even when the authors of the maps, sections, and memoirs may not have constructed the former, or written the latter, with reference to any advantage agriculture could derive from geology.

e. Even a knowledge of the faults (p. 199) which frequently traverse countries may be turned to account by an agriculturist in the drainage of land. Some of these fissures or dislocations are pervious to water, and act as main drains to portions of country, as is well known to their cost by miners in metalliferous districts. Others are filled with substances, such as clay, which prevent the passage of water on one side of the fault to the other; a circumstance highly valuable in some coal districts,—for by the intersection of several of these faults, masses of strata are enclosed by them, and if the water be pumped up by proper engines from such masses respectively, the coal-worker has only to contend with the water in any mass on which he may be occupied, a supply from other adjacent masses being cut off by the surrounding faults. It is obviously from the first kind of faults that the agriculturist can derive any advantage in the shape of drainage. Faults may be made to assist the drainage of elevated table-lands, even when their continuations across the valleys, which may cut into such table-lands, afford an abundant supply of water to the surface, as will be seen by the annexed diagram (Fig. 136). Let the line *a b* be a

Fig. 136.



level, at which a fault contains an abundance of water which is readily discharged upon the surface of the valleys *v v*, that cut the surface of land beneath this level. Then if *c d* be table-lands into which the

fault cuts upwards, the water conducted into it on such table-lands, either naturally or artificially, will tend to percolate downwards to the level, whatever its relative height may be, at which a quantity of water is sustained in the fissure, and which we have supposed to be represented by the line *a b*.

f. As the nature of a soil so materially depends upon the mineral composition and structure of the rock beneath it, an agriculturist should be alive to the advantages he may derive from a mixture of the materials of two or more rocks in producing a soil which shall be better than that naturally found on either respectively. This sometimes is done when that kind of rock commonly known as *marl* is near some soil to which it is considered a valuable addition, the marl being taken from the marl rock and distributed over the soil. In this the agriculturist does no more than add mineral matter to his soil; which, in point of fact, had not been afforded either at all, or in the proper quantity, by the decomposition of the rock beneath it. Many other valuable mixtures than these might be made with the materials of rocks, frequently adjacent to each other, either as regards the surface of land, or depth beneath such surface. Some of these mixtures are so obvious that, while examining the geological structure of some countries, we have been surprised that the accidental mixtures of the component parts of two adjacent rocks at the lines of their junction, and which demonstrate by their advantages the superior fertility upon them, have not induced agriculturists to inquire a little into the cause of them.

Carbonate of lime cannot naturally exist in soils

derived from rocks which do not contain it,—at least any portion found in them must be derived from the remains of snail-shells and the like. Now, the rocks which do not contain carbonate of lime are very numerous, particularly among a variety of the older series; and as the presence of carbonate of lime in a soil is so valuable to the agriculturist, it is obviously a mineral substance which it becomes his interest to add to one that contains little or none of it. The application of lime in its burnt state to soils is so common, that we should not notice the fact if we had not often witnessed farmers dosing their land to excess with it, without the smallest regard to any other mineral ingredient, or to those proportions of such ingredients which have been found to answer best with different kinds of cultivation. Indeed, as far as regards the large majority of farmers, they seem to consider that all plants are to be fed alike, and that what is good for one must be so for another.*

* A curious example of a general practice of adding mineral matter to a soil, without the smallest conception on the part of those who do so of what they add, is to be found in the north-western portions of Devonshire. The rock of the district is grauwacke, composed of compact arenaceous beds mixed with slate, in the greater part of which there is no carbonate of lime, while silica and alumina are abundant. The district generally is far from fertile, and makes little return to the farmer. Now, it is the common practice in that country to bring sand from the sea-coast, often many miles distant, to mix with the soil, by which the productiveness of the latter is increased. It is also the general belief that the sand benefits the soil by loosening it, though the farmers are aware that the same quantity of other kinds of sand, which may also be obtained on the coast, will not produce the same good effects. The

g. Given rocks, viewed mineralogically, affording like soils by their surface decomposition, the observer should direct his attention to the various plants which flourish best on each respectively, according to the climates in which they may be situated. This study, which may be termed geological botany, has already been advanced by many local researches, but hitherto no very extended views have been founded upon them. It can scarcely be otherwise than one in which agriculturists should be deeply interested. In this way, some plants are found to be of little value when cultivated off given rocks. The pimento or allspice tree of Jamaica may be taken as a good instance of this fact, since it is only profitably cultivated upon the white limestone formation of that island. Again, other kinds of cultivation, though they may to a certain extent succeed on several kinds of rock, are found to afford far more profitable returns upon one or two in particular. Even alluvial soils differ in value, as might indeed be anticipated, since patches of them are respectively formed of the wash, if we may use the expression, of districts which may, and generally do, vary as to the rocks of which they are composed.

Some soils are often underrated because they will not readily afford good returns as regards all, or the greater part of, the cultivation attempted upon them.

fact is, that the sand brought chiefly, and sometimes almost entirely, consists of carbonate of lime, being the triturated fragments of sea-shells thrown on shore by the breakers; and thus the farmers add, without being aware of it, a mineral substance to the land in which it was deficient, and which it required to render it somewhat fertile.

The granitic is often a despised soil in the West of England, and undoubtedly it is bad for many kinds of cultivation,—but it is found that potatoes will thrive well in it. Thus the granitic country round Moreton Hampstead in Devonshire affords the best potatoes for the Exeter market, notwithstanding there are so many localities in the district favourable to the growth of that plant. We will not, however, occupy more of our space with this subject. The connexion of the value of a soil with the kind of rock beneath it will constantly be forced upon the observer, and he has only to register and classify facts to obtain a fund of valuable information on this head.

II. *Roads.*—That the expense of constructing a new road, or of maintaining an old one in good order, greatly depends upon the kind of ground under it, upon the facility with which proper stone may be obtained for it, and upon the stability of the various cuts which it may be found necessary to make in the rocks, is well known. It is not, however, so well known that these circumstances depend upon the geological structure of a country, and that a knowledge of this structure would enable those who possessed it to determine whether one line of new road would be more costly than another; whether, when it becomes a question to patch up an old line of road or construct a new one, the one or the other will be ultimately found least expensive; and that some kinds of stone should be employed upon roads in preference to others, when several kinds can be readily obtained. The sums of money annually thrown away in this country from a want of due attention to the latter circumstance must, collectively, be very considerable.

We have seen instances in which stone was brought several miles for new roads, when a better material was close at hand. It might be true that no quarries were opened upon the better material; but any person with a little geological knowledge would point out the proper places to do so.

Roads generally are planned with regard to little else than levels and distances; and if there be a small advantage in this respect between two lines in favour of one, that line will be selected, though often a fair amount of geological knowledge would be sufficient to show that the expense, not only of forming, but also of keeping up this road, will be far greater than for the other. Good geological maps are in this respect highly valuable, as they enable those who have to decide upon subjects connected with roads to see at once the kind of rocks over which a projected line of road is intended to pass. They also point out the proximity of rocks which may afford good materials for stoning either new or old roads.

a. In cutting through stratified rocks, it should be recollected that lines of springs may be intersected which may prove injurious to the road; and also that, by inattention, a hard supporting stratum may be cut through, and the road thrown upon a clay or other loose substance, by which much unnecessary expense will be incurred in order to render the bottom firm. In all deep cuttings to lower hills, the observer should note the mineral structure of the rock cut through, so that when it becomes exposed to the atmosphere, the slopes given to the sides may be found sufficient, and the proper drainage of the road be preserved.

b. In choosing materials for roads, the observer should recollect that the stones placed on them are exposed, not only to friction, but also to the pounding or crushing action of the weights which roll over them, and consequently that a tough as well as hard substance is required. Now, rocks differ exceedingly in these qualities; and those persons who have paid attention to the kind of stones thrown on roads must have remarked how frequently hard stones are preferred by surveyors and others, when tough materials were to be obtained equally near and cheap. Thus, when flints from the chalk and chert from the green sand are found as gravels in some parts of the south-west of England, it is curious to observe how frequently the former are preferred to the latter. Rocks which are composed of substances of unequal degrees of toughness, are greatly inferior to those which are of the same texture throughout; thus granites generally afford road-stones inferior to a great variety of trappean rocks. The unpaved streets of London, those which are commonly termed M'Adamized, show how readily granite is pulverized when subjected to continued friction and pounding from the constant passage of horses and carriages over it. Such roads soon become either dusty or muddy, according to the weather. Trappean rocks have lately been imported into London for the purpose of stoning some roads; and no doubt those who have done so will soon find that, though the trappean stones cost something more in the beginning, they cost less in the end, since their durability is so much greater than that of the granites.

Those granites in which the felspar is well crystallized are the worst for the purposes of stoning roads,

since this mineral then soon crumbles under pressure, while the granites in which hornblende prevails and the felspar is more compact are the best. The trappean rocks vary considerably in their value as road-stones; even the same quarry will afford materials of different degrees of toughness. Some greenstones are particularly valuable in this respect, as also certain diallage and hypersthene rocks. When no better instrument is at hand, a large iron pestle and mortar may be used with advantage in ascertaining the relative toughness of stones. If an observer will take specimens of those intended for examination, of the size of the stones usually thrown on the roads, and then proceed to pound them, taking one specimen at a time, he will soon obtain a rough estimate of their relative values. Machines for ascertaining the relative superiority of road-stones have been invented, and there would be no difficulty in constructing those which should show their relative degrees of toughness with considerable precision. By stoning a road with proper tough materials, we not only reduce the expenses of its maintenance, but also the annual amount of hindrance caused by the more frequent supply of rough new stones, which tend so much to retard the progress of wheel-carriages, and add to the labour of the horses that draw them.

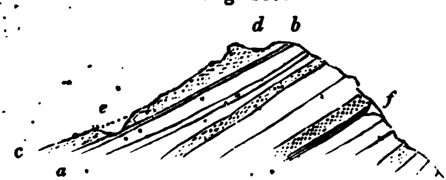
c. The difference in the durability of road materials, obtained from different beds of the stratified rocks, is so considerable, that those charged with their supply, in districts where such rocks prevail, should make themselves acquainted with their strike and dip. The instances in which much unnecessary expense might be avoided, by this simple application of geological know-

ledge, are far more numerous than would readily be credited by those who have not directed their attention to the subject.

d. In all cases, whether of the stratified or massive rocks, the observer should be careful that the stones employed for roads are not taken from the upper or weathered portions of quarries, where they have been more or less exposed to atmospheric decomposing causes, and consequently are not so valuable for the purposes required as those taken from situations where these decomposing causes have scarcely been felt.

e. In cutting roads on the sides of hills, the observer should in many cases note the dip of the beds, and their general structure, if the subjacent rocks be stratified, with considerable care; otherwise much mischief may ensue. Let the annexed diagram (Fig. 137) represent

Fig. 137.



the section of a hill, composed of beds which dip in one direction. Let *c d* be a bed of sandstone resting upon a soft clay, *a b*. Now, if a cut, *e*, be made in the hill, the continuity of *c d* will be destroyed, and the part *d* will tend to slide down upon the cut *e*. If a cut, *f*, be made on the other side of the hill, and a similar arrangement of beds exist there, no such tendency of the upper to slide upon the lower beds will be produced.

Hence, not only in such instances as that above noticed, but also in districts of certain slate and other rocks, where the cohesion between the laminæ or beds is slight, and the dip somewhat highly inclined, a preference should be given, when cuts are made for roads, to those sides of valleys or hills, as the case may be, where the strata dip inwards into the mass of the hill or mountain, as at *f*.

III. *Canals.* — In projecting lines of canal, particularly when tunnels are to be constructed, a knowledge of the geological structure of the country is not less necessary than in the case of roads. The probability of meeting with springs of water, the porous or impervious character, as regards water, of the rocks to be traversed, and the kinds of rock which will be encountered in cutting, may all in a great degree be foreseen by those who have examined the geological structure of the district. Hence good geological maps will be found of great value to those who are about to form canals. They also point out the various mineral substances which may advantageously be brought to the canal for the purposes of traffic. From a knowledge of this kind, canals have been made to pass by or through tracts of country where limestones, coal, or metals are discovered.

Canals, as is well known, are often found to be more costly than was anticipated, from the simple fact that some of the rocks traversed readily absorb water, and it therefore became necessary to incur the expense of rendering the canal-bed water-tight. Where the supply of water is limited, the presence of an extended line of porous rock is a serious difficulty. It is one, however, which might sometimes be avoided by a competent

knowledge of the geological structure of the district traversed, for such knowledge would enable the engineer so to form his plans as to avoid the porous rocks as much as possible. It should be recollected that a knowledge of the rocks on the surface will not give that of those which may be cut into the line of a canal, unless it be coupled with such information, respecting the mode in which the rocks of the district occur, that the observer shall be aware of those kinds which will probably be found at given depths in different places. A fine retentive clay may exist on the surface and rest upon a porous sandstone; and therefore, in following the levels, the former may be cut through, and the canal-bed be based on the latter.

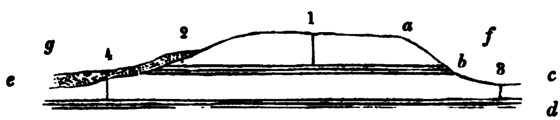
IV. *Wells.*—The geological observer will find no difficulty in applying his knowledge to the probability or improbability of obtaining water by means of wells in given situations. The most important are those named Artesian, which are perpendicular borings made into the earth to various depths, and from which large and constant supplies of water, which flow over the land in streams, are often procured in districts where this necessary of life is otherwise obtained either of bad quality or in small quantities. Although these wells are intimately connected with geological research, we must, from the want of the necessary space, neglect them,* and notice only those so common in various parts of the world.

a. The observer, neglecting those springs of water which rise from faults, and those which gush out in greater or less abundance from limestone and other

* For an account of Artesian wells, see Penny Cyclopædia.

cavernous rocks, has only to recollect that the more common springs are produced by the percolation of rain-water through porous to impervious beds, where they are stopped, and he will readily be enabled to judge of the facility or difficulty there may be in procuring water by means of wells in a given district. Let the annexed sketch (Fig. 138) represent the section of a hill composed of a porous siliceous sandstone *a*, a clay bed *b*,

Fig. 138.



a porous and somewhat calcareous sandstone *c*, and another clay *d*, and the rocks be uncovered by gravel in the valley *f*, while porous gravel is found in the valley *g*. Now, to obtain water on the top of the hill by means of wells, it would be necessary to sink through *a* to the clay *b*, where the rain-water which has percolated through *a* will be stopped. This line of water will probably be shown by a line of springs in the valley *f*; but the springs which will equally flow from it in the valley *g* (for the sake of illustration we suppose the strata horizontal) will be concealed beneath the gravel *e*, and will percolate between the clay and it to the porous sandstone *c* on that side. A well therefore formed at 2, through the gravel, would reach the same line of water as is obtained at 1, and form springs in the valley *f*. A well pierced at 3 in the valley *f* would afford the water stopped by the clay bed *d*, and the water in it would probably differ in quality from that obtained

in the line above *b*, because it has traversed a different kind of rock. To reach the same line of water in the valley *g*, it would be necessary to pierce through the gravel *e*, and the sandstone *c*; and if a thin clay parting should separate *e* from *c*, derived from the bed *b* in that direction, the well 4 would first give the line of water above *b*, and afterwards that above *d*.

b. The observer will readily conceive a variety of circumstances which may modify a supply of well-water in different localities; but by paying attention to the geological structure of each, so as to obtain a knowledge of the true relative positions of the porous and impervious beds, the influence of faults, if such occur, being duly considered, he will find little difficulty on this head.

c. Care should be taken, when the impervious bed supporting a line of water is thin, not to cut through it; for by so doing the water will be let out into the rock beneath, if that be porous.

d. Among highly inclined, and even vertical strata, water may sometimes be obtained at different levels, from the saturation of slate or other beds to a certain degree pervious to water at such levels; so that if a well be formed in such situations, the water will percolate into the cavity and fill it up to the height to which the line of saturation extends. The observer may frequently find little cavities formed in highly inclined or vertical beds of slate in the vicinity of cottages in slate districts, which are filled on this principle.

V. *Mining.* — It is not our intention to enter upon the complicated subject of mining further than to point out the necessity of geological knowledge on the part

of those who seek for metals or coals in districts where they have not been hitherto found. The sums of money thrown away, more particularly in the search for coal, which this knowledge would have saved, must be collectively very considerable. A little black shale, or piece of lignite, is often sufficient to cause the expenditure of two or three thousand pounds in localities where there is not the slightest probability of success. In the search for metals, matters are frequently not much better. It may be true, and no doubt is so, that particular metals and coal are not, as was once supposed, confined (viewing the surface of the earth generally) to rocks formed at particular geological epochs; but it may be safely stated that, in given areas, both metals and coal will be found to have given geological positions. Thus, for instance, though coal is found in the oolitic group in Yorkshire, and at Brora in Scotland, and anthracite occurs in the grauwacke of Devon, geologists are perfectly aware that good bituminous coal, fit to be worked extensively for profitable purposes, does not occur out of the carboniferous group (see p. 16) in Great Britain.

It by no means follows that the coal of Australia is of the same geological age as the coal measures of England; indeed, to suppose that all the coal, which may be profitably worked, is of the same epoch, is to imagine that, at a given geological epoch, a general entombment of vegetable matter took place in the rocks then forming over the whole face of the globe,—that this process continued uninterruptedly for ages,—and that these vegetable accumulations only took place then, and were neither formed before nor after;—a mass of absurdities

which a slight acquaintance with the present state of geology will be sufficient to expose.

a. In the search for coals, observers should be guided by the knowledge of the geological structure of given areas, in whatever part of the world these areas may occur. A knowledge of the general geological structure of eastern Australia will no doubt one day enable the geologists of that country to direct the search for coal in given rocks, and to advise the discontinuance of them in others, precisely as English geologists would advise the search for coal in the proper places, and tell those who seek for it in the numerous other situations where it has been sought, that they were only throwing away time, labour, and money.

b. With regard to metals, a knowledge of the geological structure of given areas is also requisite. As the rocks of the same epoch often change their mineral character in horizontal distances, so also their metalliferous character is found not to be constant throughout extensive areas. A due consideration of this subject would, however, lead us into discussions foreign to the object of this work. It will be sufficient to state, that the knowledge of the geological structure of the British Islands, France, Germany, or any other country, will enable the geological observers in these respective portions of the earth's surface to state, that given rocks, or given modes of their occurrence, may afford useful metals, while in other rocks or situations the search for them can scarcely be otherwise than fruitless. In England, for instance, no one would expect to discover valuable tin and copper mines in the cretaceous or oolitic groups; while the search for these metals in

Cornwall, at the junction of granite and the slate rocks, would be highly proper.

c. We may here notice the singular circumstance, that in this country, where so much capital is invested in metalliferous mines and collieries, there should be no national school or college of mines, though the great utility of such establishments is amply proved by experience in foreign countries, where for the most part the capital thus invested is comparatively trifling. British miners and coal-workers are compelled to pick up their information how they can. If by good fortune young men are placed under those who value science, and are aware of the advantages which may be derived from it, they have certainly little reason to complain; but, unfortunately, this is not the lot of the many. A College of Mines, properly conducted, would be alike beneficial to those who invest their money in mines and collieries, and those who work them. It could, indeed, scarcely be otherwise than a national benefit. Hitherto, however, the attempts which have been made to call the attention of government to this subject have been unsuccessful.

VI. *Building*.—Disregarding private dwellings, on which such various materials are employed, according to the motives that lead to their erection, it may be fairly stated, that a knowledge of the general structure of rocks, and the situations whence the best materials may be obtained, is essential to those who are either charged with or direct public works. A stone which may be sufficiently durable if plunged beneath water, may not be so when kept alternately wet and dry by the rise and fall of water in a river or on a tidal coast, or when

wholly exposed to the action of the atmosphere. A somewhat porous sandstone, for instance, may do well when kept constantly under water; but the same rock when exposed to the atmosphere, more particularly in climates subject to frost, might gradually crumble away from causes previously noticed (p. 35).

a. The observer desirous of selecting a stone to be exposed to atmospheric influences would do well to study the mode in which it is weathered in the locality whence it is obtained. He may there learn which part, if it be a compound rock, is liable to give way before such influences, and the conditions under which it does so. Granite generally is considered a proper material for national monuments. Some granites, however, though they may be hard and difficult to work when first taken from a quarry, are among the worst building materials, in consequence of the facility with which the felspar in them decomposes when exposed to the action of a wet atmosphere, in a climate which may be warm during part of the year, and cold during the other. Rocks which contain compact felspar are often very durable. Some of the *elvans*, as they are provincially termed, of Cornwall, seem to be particularly durable when exposed to atmospheric influences; for some of the old and external carved stone-work of the churches constructed with this material in that part of England is as perfect as when first put up.

Rocks which readily absorb moisture, such as many of those which are termed freestones, are exceedingly bad for the external portions of exposed public buildings; since, in countries where frosts occur, the freezing of the water in the wet surface continually peels off

the latter, and eventually destroys the ornamental work carved upon it. It should be recollected that freestones, so termed because they are easily worked, are often valued because they may be cut readily when first taken from the quarry, and subsequently become harder when exposed to the atmosphere; and that this quality arises from the evaporation of the water contained in the stone when forming part of the natural rock. Now, some of these freestones again readily absorb moisture, while others do not: hence the latter should be preferred; and an observer should ascertain this fact by experiment before any given freëstone is selected.

Some freestones are formed of particles of sand cemented together by different substances, the cementing matter being sometimes siliceous, at others calcareous, and at others again formed of oxide of iron. In the first case, the freestone would not suffer from the chemical action of atmospheric influences upon it; while in the second, rain-water containing carbonic acid would tend to dissolve the calcareous matter, and deprive the sand of its cement; and in the third, the action of atmospheric influences would tend to render the material unsightly by staining it with iron rust.

The little attention that has been paid in the erection of national monuments in this country to the durability of the materials of which they are constructed, is well known. There is no want of good materials, if they would be sought out; and it often occurs to the geologist to find them. A more beautiful stone for public works can nowhere be obtained than from a mass of white granite near Okehampton in Devonshire. Judging from the weathered character of this rock, it

must be extremely durable. It is composed of white felspar, quartz and mica, and looks as white as statuary marble. Hitherto, we believe, this beautiful material has only been formed into one or two chimneypieces.

b. In selecting stone for artificial harbours, breakwaters, quays, and bridges, the observer should note those kinds which best suit the different parts of the work to be executed. Where a pier or breakwater has to resist the action of heavy breakers, charged with the pebbles of a beach, a harder material becomes necessary than when it has only to encounter the action of breakers not so charged. In both cases the weight of a stone is an important consideration, since the greater the weight in the same bulk, the greater the resistance to removal from the blow of a breaker, other things being equal. An observer, therefore, should ascertain the specific gravity of a stone he may be desirous of employing. Several kinds of stone, otherwise equally good, may vary much in this respect; so that two piers of given dimensions may differ considerably from each other in weight according to the materials employed.

In constructing piers, quays, and bridges, where the water-level varies, materials which may be good for one part of the work may not be so for other portions. Many rocks which may be advantageously employed in situations constantly under water, will be found liable to decomposition when exposed to the atmosphere, particularly in those portions kept alternately wet and dry by the rise and fall of tides, or other causes producing changes in the level of the water. An observer may often obtain information on this head by studying the condition of rocks on the banks of rivers and on the sea-